Volume G8, Number 1, May 1959

BULLETIN OF THE RESEARCH COUNCIL OF ISRAEL

Section G
GEO-SCIENCES

Bull. Res. Counc. of Israel. G. Geo-Sciences

Page

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M. AVNIMELECH

1899–

ON HIS SIXTIETH BIRTHDAY

A review of the work of a scientist in Eretz Israel during the years before the establishment of the State of Israel must be viewed within the framework of the research which was then being carried out.

In 1929 Mr. M. Avnimelech started his work at the Hebrew University as laboratory assistant. At that time, the Department of Geology comprised one geologist and occupied two rooms. This state of affairs remained unchanged for a long time, with only a slight increase in personnel. Budget and purchasing power were on a minimum scale. The research worker had at his disposal only very limited means. There was no way to allot any funds to his specialization. The young staff had to provide for their post-graduate work by themselves. Thus every member of the young geological department was trained in all branches of geology, including Paleontology and Mineralogy–Petrography.

The work of M. Avnimelech was at first devoted to zoological research: land snails of the Judean Mountains. His survey in the districts of Artuf and Megiddo in 1936 was the basis of his doctoral thesis, which he presented at the University of Grenoble (France). Similar field-work was carried out by him in the Ephraim Mountains. Even petro-genetic problems were taken up by him. With the gradual expansion of the Geology Department, the sphere of his scientific work increased from year to year. During the Second World War and the years preceding the establishment of the State, M. Avnimelech devoted himself more and more to the problems of Paleontology. He also published the results of research work in the field of Micropaleontology and the Paleontology of other lower organisms, which in fact became his preferred research subject. In his numerous papers on fossil groups from Palestine and adjacent countries, he introduced many new viewpoints and methods of examination, e.g. on Pteropods, Serpulids, Scaphopods, Nautiloids, Belemnoids, Anthozoans and others. In his micropaleontological research he contributed significant studies on Foraminifera and Microfacies. Similarly, he paid a great deal of attention to the stratigraphical problems of the Early Tertiary, Jurassic and Triasic.

More recently he has published the results of his research on Vertebrata, especially the fish remains of the Senonian. and the continental Neogene. In connection with his studies of the Quaternary, he studied the fossil mammals of this period also, and his discussions on the Quaternary and Neogene formations in his later

works are probably his most important contributions to the stratigraphy of the country. Finally, a number of problems in connection with sedimentation and lacunas were discussed, the paleographic and tectonic importance of these still being the subject of recent studies. In collaboration with his students he directed much attention to the study of the Triassic and Jurassic occurrences in the Negev.

In addition to his numerous and diversified scientific works, M. Avnimelech has published many popular and semipopular articles in various magazines, daily newspapers, lexicons, etc., on problems of agriculture, colonization, afforestation, soil, and conservation of natural resources. The list below, however, represents only his purely scientific publications and provides a good insight into his varied interests and research activities.

On his 60th anniversary, M. Avnimelech may well look back with satisfaction on his 30 years of activity at the Hebrew University. In addition to his research work and his indispensable contributions to the building up of paleontological teaching at this institution, large portions of his time have been devoted to the establishment and preservation of collections and the organization of the libraries at both the University and the Geological Survey of Israel. He also founded the micropaleontological laboratory of the Geological Survey.

His 60th birthday thus quite properly becomes a day of appreciation for a devoted research worker who has so markedly contributed to the progress of geological research and teaching in Israel.

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GEOLOGY AND OIL EXPLORATION OF ISRAEL *

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ABSTRACT

Israel's structural bodies—anticlines, synclines and horst-gräben (blocks)—have been tested by more than 30 wildcats (deepest 4000 m) in the course of the past few years. The anticlinal tests usually started in the Upper Cretaceous crests. They reached or penetrated the pelagic Jurassic limestone-dolomite (1500–1000 m thick) in Central-Northern Israel, while in the Negev upland they met with limy, marly, sandy epicontinental series or continental sandstone of Jurassic–Triassic and (at Sinaf) of Paleozoic age. However, no fluid producers were found. The only oil field—Heletz (and Brur)—is thought to lie in a subsurface tilted half-horst structure bordering on the Mediterranean Neogene graben of Ashkelon. True larger gas accumulations now tested at Zohar, and expected to become exploitable, belong to an anticlinal structure. But, this and other showings of this peculiar well may be attributed to lateral migration deriving from the structures and source-beds of the Dead Sea graben, which are only a few miles away from Zohar. Good and partly very good shows were, however, frequently discovered in fractures and joints of Jurassic limestone. Sealed by an Infra-Cretaceous shale cover, they must once have formed quite substantial oil accumulations originating, in the writer's opinion, during the Lower Mid-Tertiary orogeny. The source-beds are possibly of pre-Jurassic age. Graben-structures were drilled in down-sunken (Engedi, Massada) and in uplifted blocks (Jordan No. 1 and Debora, the latter in an uplifted half-anticline next to the Tabor graben). Apart from the producing areas, all the mentioned wildcats located on graben-block structures are rich in excellent and partly "living" fluid and viscous shows. Oil and shows are thought to have originated by lateral migration from Upper Cretaceous and/or Oligocene down-warped and down-sunken graben sediments sealed by marine or continental cover beds (of Neogene-Quaternary age).

In view of past drilling experience, testing of graben structures in coastal and off-shore areas, as well as in inter-mountain depressions (Jordan–Dead Sea and Tabor–Esdraelon), seems to hold greater prospects than anticlinal testing.

This concept should dominate our line of thought in further oil exploration. Yet, recovering of the bounded and fossilized semi-liquid hydrocarbons in the highly fractured Jurassic limestone of these anticlines has to be considered and economical methods worked out.

SOURCES OF INFORMATION

Following the Fohs report in 1929, discussions on the oil possibilities of Israel and former Palestine went on for some time. However, intensive oil exploration of the country started only after the publication of Ball's "Oil prospects of Israel" in 1953. The reader is referred to this and to Renouard's "Oil prospects of Le-

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banon" (1955), both of which give a general introduction to the facts and problems of our Levant region.

A historical review of the previous oil research, bituminous surface seeps and impregnations has been published in the writer's "History of Mineral Research in Israel" (1954); the extensive bibliographical list should be used as addenda to the references made in the present paper.

New geological maps were recently published in detailed sheets, on different scales, by the Ministry of Development (Jerusalem). A compiled map for the whole country was issued by the Survey Department (Tel-Aviv).

A great amount of drilling and other technical operations was reviewed (by Grader) in the July 1958 *Bulletin of the American Association of Petroleum Geologists*. For unpublished information the writer is greatly indebted to the following oil companies which put at his disposal the composite logs of their deep drillings : Israel–American Oil Corporation (I.A.O.), Israel Continental Oil Company (I.C.O.), Israel Mediterranean Petroleum Company and Pan–Israel Oil Company (I.M.P. & P.I.O.), Jordan Exploration Company (J.E.C.), Judea Petroleum Company (J.P.O.), Lapidoth and Israel Oil Prospectors (L. & I.O.P.), Naphtha Israel Petroleum Corporation (N.I.P.).

Unpublished information on outcrop sections, furnished by the writer's students and colleagues, are gratefully acknowledged. Finally, the author has to thank the Israel Continental Oil Company for its kind permission to publish those of the results of his researches which he has carried out in the service of the firm.

Structural and Stratigraphic Introduction

Israel, as part of the Levantides fold belt (Picard 1958) is crossed by a series of frequently asymmetric anticlines-synclines mostly of NE–SW direction. They are best preserved and of distinct Jura fold morphology in the Negev and Judean upland (Figure 1).

The folds received their decisive pattern in the late Oligocene, but were uplifted and block-faulted in two main episodes : in early Miocene and in early Pleistocene. Meridional gräben of regional size developed in the west, hidden now by the Mediterranean sea, or in the east, originating the Jordan–Dead Sea–Araba Rift valley (Figure 2).

Inter-mountain fault-troughs, such as the Esdraleon and Tabor depression, as well as minor horsts, gräben and tilted blocks, are characteristic morpho-tectonic features of Northern Israel.

The structural pattern of Israel has been discussed in recent publications (Picard, Ball, Bentor–Vroman) to which the reader is referred.

The principal rock-exposures belong to the Upper Cretaceous-Cenozoic. The rare outcrops of Lower Cretaceous and pre-Cretaceous formations are attached to the lower flanks of gräben and uplifted blocks and to a limited number of erosion cuts and cirques.

Since the beginning of the Paleozoic the country was under a periodic struggle between the geosynclinal reign of the Tethys in the West and the continental influence of the Arabian shield mass in the east. Up and down movements of the shelf and continental slope, most likely with deep-seated faulting (accompanied by Mesozoic intrusiva and extrusiva), rarely raised the country above sea level. Orogenic folding is thought to have started in the Cretaceous but is only clearly definable with the complete retreat of the Tethys in the Oligocene. It is during this period between the end of the Nummulitic and the beginning of the Upper Tertiary that our region turned into a Mediterranean inland sea landscape abundant in gulfs, lagoons, peninsulas and isthmuses with typical semi-marine, semi-continental sedimentation.

Basement

Upper Tertiary to Recent faulting and uplift has led to many exposures of the Precambrian basement rocks along the western flank and border of the Araba graben, on the south-eastern corner of the Dead Sea, in the Eilat area and the eastern Sinai.

Varieties of granites and granite-porphyries, syenites, diorites and gabbro, interchanging with gneisses and micaschists constitute the principal plutonics and metamorphics of the basement rocks. There also occur volcanic tuffs and lava sheets but far more frequently acid and basic dykes which have swarmed through the whole crystalline complex as well as through a series of non-metamorphosed sediments termed Saramuj series. The Saramuj series consists principally of multicoloured conglomerates analogous in rock-character and deposition to the Molasse and Verrucano of the Alps. Like these alpine formations the Saramuj series are of simple fold structure, giving reason to assume mountain-building during the late Precambrian. Our Precambrian fold mountains were then levelled down on such a regional scale that only few monadnocks remained on an enormous erosion and abrasion surface.

Asphalt or oil seepages have not yet been discovered in the basement complex.

Paleozoics

The few marine *Lower Paleozoic* outcrops which became known in the areas of Timna-Eilat in Israel and of Petra, of Wadi Hasi and Zerka Main on the Transjordan border of the Dead Sea, all reveal thin beds of shallow epicontinental limestone, dolomites, shales and littoral sands intercalated between, and overlain by, continental sandstones, the latter attaining several hundred metres of thickness. (Except for an asphaltic film in the Lower Cambrian Redlichia-bearing limestone at the east side of the Dead Sea graben, near Zerka Main, no other oil indications are recorded from the marine Paleozoic ouctcrops).

Thus the Paleozoic era of our region was under the predominant influence of the Arabian landmass. Only in the Mesozoic era did the oceanic Tethys (geosyncline) more and more impose itself. This prevalent continental but also littoral sandy complex are all included in the term Nubian sandstone.

The difficulty of age assignment of the *Nubian sandstone* (NS) remains when we study, at the same outcrops of the Araba and Dead Sea graben, the upper section of the "Nubian" complex. Thus in the Nubian stndstone canyons and on the steep western slopes of Moab and Edom, of Midian (Hedjaz) and in the Eilat area opposite (foremost in the half-erosion cirque of Timna), Triassic and Jurassic marine interbeddings are remarkably absent. Here, the massive sandstone rests directly on the Precambrian or on thin marine Cambro–Silurian beds and is directly overlain by marine Cenomanian strata. In these parts of the country we may therefore assign to the Nubian sandstone any age from Paleozoic to Mesozoic. Indeed, fossil plants found in the uppermost layers of the sandstone are of continental Lower Cretaceous, i. e. Wealden character.

The Sinaf wildcat, halfway between Eilat and Ramon, revealed a 900 m nonfossiliferous Nubian sandstone group which apparently represents most of the Paleozoic and Triassic (if not also Jurassic). This major Nubian section is followed by 35 m of dolomite of Upper Triassic or Jurassic age. "Nubian" sandstone lies above the dolomite and is covered by marine Cenomanian. We concur with the view of Lapidoth's geologists and refer the Nubian sandstone here to the Lower Cretaceous.

Asphalt and oil seepages and impregnations have been known for a long time in the Paleo–Mesozoic Nubian sandstone exposed on the eastern shore and mountain border of the Dead Sea. The most impressive ones occur south of the Arnon river, at Ain Humar (opposite Engedi), where next to an oil spring the writer observed the cracks of the sandstone fiilled with yellowish ozokerite. Except for the Jurassic bottom sandstone of Zohar, none of the Nubian sandstone outcrops and wildcats of Israel has so far revealed these hydrocarbon indications.

Triassic

Genuine *marine Triassic* outcrops have only become known from the surroundings of the northeastern corner of the Dead Sea and from deeper wadi cuts of the Yabbok River in Jordan. In the High Negev of Sinai and of Israel, Triassic is exposed in the erosion funnels of Aref en Naga and particularly of Ramon. The predominant limy, occasionally marly beds of 110 to 170 m thickness display great lithological affinities with the "germanic" epicontinental Triassic. Its Middle Triassic fauna, however, contains sufficient Mediterranean elements (latest discussion: Brotzen, Parnes). Quasi-continental conditions dominate again in the superjacent 100 m to 200 m thick masses of gypsum-evaporites, in the warved faunistically sterile dolomites and (Keuper-like) variegated marls.

The deepest oil show in the Massada wildcat derives from an "intra-formational anhydrite breccia" which tops the dolomite section referred provisionally to the Upper Triassic. The recent Kurnub wildcat drilled by the Israel Mediterranean Corporation showed a total thickness of 770 m Triassic. These higher figures also show up in the Rekhme testhole underneath the Jurassic. Avnimelech (1958) suggests

543 m thickness for the marine Triassic of the Rekhme cuttings, and attributes the entire Triassic of Rekhme to the "pelagic deep sea". In the Kurnub hole a 850 m thick series of shale, limestone and sandstone was drilled, resting on an igneous socle. Although not containing fossils this partly marine, partly continental section below the Kurnub Triassic should be representative of most of the Paleozoic. The exposures below the marine Middle Triassic consist of several decimetres of sandstone with shales and *Lingula* still indicating marine shore environment.

Jurassic

Marine Jurassic is exposed in the anticlinal cores of the Ramon erosion-funnel and the erosion cirques of the Maktesh Hagadol (formerly the Hathira of Kurnub) and Maktesh Hakatan (formerly the Hadhira) and possibly in the lowermost beds of the Wadi Maleh (south of Beth Shean).

Yet, none of the exposed limy and marly formations of the Jurassic in the Negev are completely devoid of sandy intermixtures, thereby demonstrating shallow sea water conditions in the vicinity of a dune-framed continent. At Ramon terrestrial influence is also marked by residual deposits of bog-iron and flint clays (up to 55% Al_2O_3) in the Jurassic–Triassic transition beds and, furthermore, by about 400 metres of continental Nubian sandstone, rarely intercalated with thin layers of marine Jurassic.

In the Kurnub deep-test, the Nubian sandstone section of the Jurassic, equally interbedded with thin oolitic-dolomitic limestone and lignitic shales, attains 800 m thickness. Resting on Triassic evaporites and covered by 400 m of marine Upper Jurassic limestone, this "Nubian" section is of Middle to Lower Jurassic age.

At Rekhme, 10 km W of Kurnub, the Lower Mid–Jurassic sandstone seems to be largely replaced by sandy shales and marls and intercalated thin beds of oolitic limestone (somewhat resembling in lithofacies the Aptian–Barremian strata of the Lower Cretaceous), attaining 1000 m thickness. The wildcat of Zohar (formerly Zuweira), 44 km NE of Rekhme, is of similar character and 700 m thick, but the last 100 m are of "Nubian" sandstone type. This sandstone is underlain by 280 m of dolomites with some shales and gypsum in cracks and bedding planes which could belong to the Triassic.

Massada, 16 km NE of Zohar, revealed a surprising Jurassic series of 700 m prevalent oolitic, non-oolitic and dolomitic limestone, with insignificant sandstone intercalation in the middle section and some shales. This limestone complex is underlain by a 5 m intraformational breccia of anhydrite followed below to the bottom by 220 m dolomite referred by "Lapidoth" to the Triassic. The Jurassic of Massada is thus principally developed in the calcareous deep-water facies otherwise found in the drillings of Judea, Coastal plain and Northern Israel.

On the opposite graben flanks of Transjordan between W. Hasi and Zerka Main, only 15 to 20 km East of Massada, the Nubian sandstone complex of several hundred metres is devoid of marine sediments. Triassic and Jurrassic marine in-

terdigitations appear only further north, best known from the 200 m reduced section of the Yabbok or Zerka. We may, therefore, assume a very narrow shelf and littoral zone in the central part of the present Dead Sea*, the Jurassic of the Judean Desert being most likely deposited in the more open oceanic trough of Massada.

Contrary to that, the shallow epicontinental shelf becomes very wide in the Negev and extends to the Sinai (Figure 3). Some 1300m of Jurassic sand and shales dominate over the interdigitating limestone beds found in the El Khabra well (Standard Oil of New Jersey, see Ball), 60 km due W. of Rekhme. The 1000 m exposed Jurassic at Jebel Maghara in northwesternmost Sinai is developed in the same facies.

However, Beeri, in the Southern Israel Coastal Plain, 64 km NW of Rekhme, had drilled a 1300 m section of overwhelming calcareous rocks, with only a few metres of sandstone. Halutza, 39 km NW of Rekhme, had not tested the Jurassic. Hence, we can only suppose that the transition zone from a prevalent limy to a prevalent sandy-shaly facies lies somewhere in the Beersheba-Halutza region and turns from here towards the Dead Sea near Massada.

Many wildcats of the coastal plain between Beeri and Petah-Tikva were bottomed in the Lower Cretaceous or at best have touched the Upper Jurassic. Heletz No. 22 was, therefore, drilled to explore Jurassic and older beds and found a 2500 m hard limestone complex with a more chalky-marly part of 100 m top section and a 700 m dolomitic part in the bottom. There exists then in the Heletz region a duplication, if not a triplication (depending on the age assignment of the dolomitic lower portion to Triassic) of the Jurassic thicknesses noticed also in the transitional overlaying black shale formation to be discussed below. Increased thickness, hand in hand with more and more calcareous deposition from south to north and east to west, induces us to assume a growing deepening of the geosynclinal trough in these directions. Indeed, the Motza well, located at the top of the Judean Mountains (altitude of 690+ m), revealed a Jurassic limestone and dolomite column of 1100 metres. (Anhydrite veins are here of secondary nature; they were formed probably due to interaction of sulphur which derived from the asphalt occurring in the same strata).

Tests which deeply entered into the Jurassic were made in the Carmel and showed limestone and dolomite of 1500 m at Haifa and 1000 m at Zikhron Yaacov (Carmel No. 1) which may well continue in greater depth. We are doubtless here in a deeper water trough which continued to north and northeast and deposited huge calcareous sediments exposed as Jurassic limestone massifs of Lebanon and Hermon. The Jurassic limestone again surpasses 1500 m. In the Hermon the Middle Jurassic is slightly sandy, and the Liassic, according to Vautrin, continental.

*) Provided one does not adhere to the hypothesis of horizontal shifting of the graben flanks.

We may then assume that the epicontinental shaly-sandy shelf situated in the Golan and Hauran district (south of the Hermon) extends in the south to the Yabbok (Zerka) river.

We arrive thus at the conclusion that during Jurassic (see Figure 4):

1. Northern and Central Israel was ruled by a deep-water sea, the chemical precipitation of which produced a mighty calcareous sequence best termed *Lebanon facies.*
2. Southern Israel or Negev, south of the line Gaza–Beersheba–Dead Sea, was dominated by the shallow sandy and marly shelf facies best termed (Jebel) *Maghara facies.*
3. Southern Negev, Moab and Edom in Transjordan were under the continental reign of the desertic Nubian sandstone facies which already existed in the Triassic and Upper Paleozoic and which we had named *Arnon–Petrafacies* (1953).

Infracretaceous

The top strata of the calcareous Lebanon facies, the former *Glandaria* or *Cladocoropsis* (Lovcenipora) limestone, referred by many to the Kimmeridge–Lusitanian, is usually separated by a sharp formational cut. This is noticed in the Kurnub–Ramon region by overlying continental sandstone, in the Hermon and in most of Israel as far south as Zohar and Halutza (northern Negev) by overlying lagoonal(?) dark and black shales. The age of this shale complex has been given as Jurassic Lusitanian–Portlandian (Renouard) but also as Lowermost Cretaceous Berrissian–Valanginian (Reiss). Its frequent interdigitation with volcanics in Galilee (Debora, Haifa Bay) and Carmel (Haifa, Caesarea) and/or with intercalated limestone beds (of Jurassic type) gives this formation an Infracretaceous age position. The Infracretaceous shale group is exposed in 200 m thickness in the Hermon. All our knowledge derives therefore from wildcat drillings which have, in general, revealed a thickening from East to West, especially rapidly in the Coastal plain sector. The isopach picture (Figure 5) is, however, still very tentative and there are certain "anomalies", such as the great thickness at Motza (240 m), the small thickness at Debora and Haifa due to the interchange of volcanic material. The latter "anomalies" could naturally be explained by submarine "highs", especially when connected with volcanic sea-bottom topography. The black (bituminous?) shales were deposited (in contrast to the open-oceanic Kimmeridgian) in a bay-like environment where black pyritic mud and iron oolites were formed. The Kimmeridgian and Infracretaceous volcanics demand deep-seated faulting and thus block movements which led to upheaval in Galilee and Carmel or in the northern Negev around Kurnub and Ramon. Neither the drillings of the Coastal Plain nor of the Judean Mountains (Motza) and of the Negev east of Kurnub–Ramon (Massada to Sinaf) have so far revealed Uppermost Jurassic or Infracretaceous volcanics.

In Lebanon and northern Israel volcanics are also interspersed in the Middle Jurassic, though in the case of sills or dykes their age might be younger. The most impressive volcanic material is known from Debora (near Mt. Tabor), where the well was bottomed after having drilled through nearly 800 m of diabasic and dacitic lavas (determination by Oppenheim) and agglomerates (rarely interstratified by limestone or blackish shales).

The other area of magmatic activity lies in the south at Ramon. Here, numerous trachytic dykes and sills cross and penetrate both the Triassic and Jurassic. Volcanics occur again in the Lower Cretaceous sandstone but are of continental basaltic type. Still somewhat uncertain is the age of the syenitic plutonic core of the Ramon anticline which contacts or underlies the Triassic sediments. This also applies to the plutonics in which the Kurnub well was bottomed and to some magmatic rocks found in the Arnon–Petra sandstone on the eastern shore of the Dead Sea.

A 30 m thick "weathered monzonite–diorite", according to Naptha Co.'s log, intercalates the 110 m Jurassic basal sandstone of the Zohar well.

As an after-effect of the tectonic movements and volcanic activities at the end of the Jurassic, which indicate upheaval followed by strong erosion and gravel accumulation, we have to mention the sporadic outcrops of conglomerates found in the Lebanon first discussed by Vokes.

Except for Rekhme, where a gravel bed in the marine Uppermost Jurassic (*Kurnubia*) is registered in the I.A.O. company's log, none of the wildcats of Israel which drilled in the Upper Jurassic or lowermost Cretaceous records such coarse clastics. At the exposures of Ramon, however, conglomerates are encountered which introduce the Cretaceous.

Oil Indications in the Jurassic and Infracretaceous

Many a wildcat which penetrated the Kimmeridgian and older Jurassic limestone or dolomite (more rarely sandstone) discovered various kinds of shows from hard asphaltite to viscous tar, fluid asphalt and oil stainings. Cracks and joints of asphaltite were first discovered in 1956 in the Jurassic of the Carmel (I.C.O.) at Zichron Yaacov (Carmel No. 1) and later at Caesarea. No shows, however, are recorded in the 1470 m Jurassic limestone of the Haifa well (P.I.M.O.). Asphaltic signs and odour were noticed in the bottom beds of the Haifa Bay wildcat, at Kurdaneh, before the well was suspended. At Debora, near Mt. Tabor, "bleeding" cores and waxy and viscous asphaltic matter were impregnating the pore-spaces of the complex and its interstratified limestone as well as calcite veins.

The 1100 m drilled section of Jurassic limestone and dolomite of Motza is extremely rich in asphalt veins and oil stains, whereas the covering Infracretaceous shales and the Mid-Lower Cretaceous formations are completely devoid of indications. At Zohar, methane gas appears in the Upper Jurassic, the production of which has been estimated at an average of 50,000 cubic feet per day. The same

well showed oil and asphalt indications in the Middle and Lower Jurassic dolomite and sandstone. Beeri revealed gilsonite at the bottom of the Malm limestone. At Heletz No. 22 disappointingly few "spots of asphalt" are mentioned in Lapidoth's log as deriving from the middle part of the otherwise empty Jurassic limestone complex of 2487 m drilled thickness; the only better shows occurred here in thin "Heletz" sandstone strata of the Lowermost Cretaceous. The exceptionally rich shows found at Massada in many formations from Quaternary to Upper Triassic are due to the special tectonic circumstances under which migration took place in the fault-blocks of the Dead Sea graben (see Figure 1), and which also gave origin to the aforementioned seepages of the Paleozoic Nubian sandstone seen along the Transjordan border of the graben.

In north Lebanon, according to Renouard, "diffuse impregnations occur along tectonic accidents (faults, fractions, breaks)", i.e. under conditions equal to the seepages along the Dead Sea rift valley.

In view of so many "shows" found in the Jurassic limestone, the question arises whether some of our deep tests were not bottomed too soon when reaching either the top Jurassic or the Infracretaceous.

This might be the case at Sdot Akiba (88 m hard limestone), Safit (100 m oolitic limestone), Hulda (60 m dolomite and limestone). Gan Yavne (86 m limestone and dolomite with thin shale intercalations), Haifa Bay (175 m limestone and shale with 15 m dolomite at base), Revaha (190 m limestone with chalk), King David (90 m limestone and shale), Petah Tikva (156 m limestone, shale and sand). Other wildcats, like Halutza, Heletz, Bror 2, Tlamim, Negba, Zikim, Mazal, Jordan and Engedi never entered Jurassic at all.

The complete absence of petroleum indications in strata referred to Jurassic and Triassic but also to the Cretaceous at the Rekhme wildcat, which was located on a distinct structural high-point, is most striking. It adds to the difficulty, already encountered when interpreting the stratigraphic data, of obtaining a proper conception of this well.

The negative showings at Kurnub (Hathira) are less surprising in view of an uncovered 200 m section of Upper Jurassic and the absence of an Infracretaceous black shale cover. Nor could one expect too impressive results from the Sinaf well which met with a prevalently continental Nubian sandstone facies representing formations from Lower Cretaceous to the Paleozoics.

The tight black shales of the Infracretaceous as well as their interstratified limestone beds are devoid of hydrocarbon "shows".

Vertical migration may have found a sealing bar in the black shale cover. It would explain the frequent showings in the Jurassic (Zohar, Beeri, Motza, Caesarea, Carmel, Haifa Bay, Debora) as against paucity of shows in the Cretaceous–Tertiary in one and the same drilling section. In the case of Massada, where shows occurred in all Meso–Cenozoic formations, or in the case of Heletz (No. 22), where shows were principally restricted to the Lower Cretaceous sands, lateral migration

may have played a rôle. The source for many Jurassic shows would then have to be sought in the Triassic or, more likely, in the Paleozoic, whereas for the shows of Massada and possibly also for Heletz any well-covered bituminous formation from Tertiary to Paleozoic (e.g. Senonian, Neogene) in the Jordan graben or in the huge Tertiary fillings of the Mediterranean fault-troughs might be the responsible mother rock.

Lower Cretaceous

A division in lithology from limestone in the West to marl and sand in the East is again noticed in the Lower Cretaceous. However, there is, in contrast to the Jurassic, a stronger west shifting of the sandy facies in the Lower Cretaceous. Thus, Jordan is completely in the realm of continental Nubian sandstone, while shelf formation prevails over most of Israel, leaving for the pelagic lime deposits the small strip of the Carmel (see Figure 6).

The exclusively *continental* sandstone is known in Israel only from the exposures near Eilat in the southernmost Negev. The 200 m thick section of Lower Cretaceous drilled at Sinaf already includes marine interfingerings of sandy shales. At Ramon a 40 m thick marine Albian rests on 200 m Nubian sandstone with basalt and gravel near the base. At Makhtesh Hatzora (Hadira) the 385 m Nubian sandstone shows one (or two?) very thin intercalations (Vroman and Bentor); at Makhtesh Hathira (Kurnub), 20 km further west, these Aptian–Albian (Avnimelech, Parnes, Reiss) intercalations comprise one-quarter of the 320 m thick Lower Cretaceous "Nubian". In general, the Lower Cretaceous continental sandstone appears at the base with a Weald flora and kaolinic clays and, at the top, with marine glauconite sands. These Albian greensands were also found at Rekhme.

The Lower Cretaceous of Massada (300 m), Zohar (435 m) and doubtless of Rekhme is prevalently developed in marine facies, although never without abundant intermixing of sand.

Towards el Khabra and Halutza the marine Lower Cretaceous increases in thickness to 900 and 1000 metres (Figure 7). Marl, limestone and dolomite prevail in the Albian–Aptian, and sands in the Barremian. We are here in the genuine epicontinental "Heletz facies" which is spread over the Shephela and Negev coastal plain, but has also been encountered in the mountainous region as far east as Motza. Due to the producing "Heletz sands", we find here the densest network of Israel's wildcats and wells.

In the writer's Report to the Government (April 1956) on the Lower Cretaceous of the King David well, situated near Heletz, the following stratigraphy was proposed :

1. Albian—a dolomitic and (mostly non-oolitic) limestone complex, occasionally with chalk and shale; thickness 200–300 m.
2. Aptian to Barremian—a prevalently oolitic limestone complex, with shale in the middle part and rarely sands; thickness 250–350 m.

3. Neocomian—sandstone with some shale and oolitic limestone, thickness 200–300 m.
4. Portlandian to Kimmeridgian—oolitic limestone and black shale complex (very rarely sandy).

In Grader and Reiss's composite log on the Lower Cretaceous of the Heletz area (1957), a related sequence has been amended by the inclusion of microforaminiferal zones :

1. Albian with *Nezzazata–Globigerina.*
2. Aptian—main *Orbitolina* zone and start of *Choffatella.*
3. Barremian—main *Choffatella* zone and start of *Trocholina*
4. Hauterivian to Valanginian—main *Trocholina* zone.

The proper black shale complex, still with *Trocholina* but free of *Choffatella,* was referred to the Berriassian. Following a proposal by Rutsch–Bertschy, the term Neocomian—hitherto in use for zones 3 and 4 in the Lebanon—is now omitted. The new stratigraphic scale still meets with difficulties in view of the lack of determinable macrofossils, especially ammonites. Iron–oolitic beds are known in many horizons from Aptian to Infracretaceous. Lignite and pyrite are frequently interspersed in the Barremian to Valanginian (former Neocomian) strata. The average thickness of 900 m in the coastal sections reaches a maximum of 1000 m in the foothills of Hulda and the Judean anticlinal region of Motza. Such an increase in thickness was also noticed in the Infracretaceous discussed before; it suggests continuous and stronger subsidence and speaks against the formation of "orogenic" compressional anticlinal structures in Lower Cretaceous or Jurassic time in this area, which is also indicated here by the absence of proper and regional unconformities.

In the Gan Yavne well, dolomite replaces the oolitic limestone so well-developed in the Aptian of the "Heletz facies". On the other hand, oolitic limestone with thin alternating beds of sand and shale now distinguishes the Barremian. (Secondary gypsum and H_2S gas is another peculiarity of this well).

The final change to a dominant *calcareous* facies from Albian to the "Hauterive–Valanginian" is evidenced in the wildcats of the Carmel at Caesarea and Zichron Yaacov. In a 650 m thick group of oolitic (occasionally dolomitic) limestones there occur insignificant shale intercalations, practically without sand except for the base. These 13 m of fine-grained sands, referred by us to the Barremian, are still intermixed with limestone. The underlying 150 to 175 m thick black shales with oolitic limestone may well belong to the transitory Hauterive–Valanginian (zone 4). We would then arrive at a round figure of 850 m thickness for the Lower Cretaceous of the Caesarea, Carmel, Haifa and Haifa Bay wells (excluding the shale and volcanic series of the Infracretaceous) (see Figure 7).

The predominance of the Carmel limestone province has ceased to exist in the Haifa Bay well, at Kurdaneh. Sand strata, but even more *shales,* indicate the "Galilean facies", though the Kurdaneh Lower Cretaceous is still entirely marine. In the outcrops of the Aptian–Albian in Central and Eastern Galilee the superiority of the marl (shale) sedimentation is especially felt. Thick bedded limestone intercalations protrude on the surface as abrupt falaises, the "muraille de Blanche" and "Zumoffen" of the Lebanon investigators.

A conspicuous landslide topography becomes a characteristic morphological feature of all the principal Albian–Aptian outcrops: Debora, Beth Natufa, Mughrar, Rami, Menara. It contrasts with the sharp slope-profiles of the Weald Sandstone ("Kurnub sandstone") exposed in the erosion cirques of the Negev: Hadhira, Hathira, Ramon, Timna. The decrease in thickness, from Kurdaneh (Haifa Bay well) to Tiberias (Jordan No. 1), of the Albian to top Infracretaceous (black shale complex) and Albian to top Nubian sandstone respectively is from 850 m to 550 m, i.e. 15 m to 1 km. A still greater reduction in thickness (5 m to 1 km) is displayed by the Mid-Aptian "Blanche" horizon: 150 m at Haifa Bay, 75 m at Beth Natufa and 45 m at Tiberias and W. Faria.

The stratigraphic sequence of the Lower Cretaceous of Eastern Galilee and Eastern Samaria (as far south as W. Faria) corresponds very much to that of the Hermon–Lebanon. Progressive sedimentary evolution is found from the early or continental stage to epicontinental and finally to quasi-pelagic conditions. Thus, the Weald type of Nubian sandstone drilled at Tiberias, exposed at Menara and (with basalt inclusions) at W. Faria, which we regard as the equivalent in time of the Valanginian–Barremian in the West (Heletz to Kurdaneh), becomes sandy-marly littoral in the Lower Aptian. Upon a short period of undisturbed shelf conditions, represented now as "Blanche" lithographic limestone, there follows in the Upper Aptian a more turbulent yet still shallow water sedimentation, giving origin to the variegated marly couches à Orbitolines, with interbedded, sandy, detritic and particularly iron-oolitic limestones. In the Albian, the coastal influence gradually ceases. Marls are rare and found at the base of the formation (*Knemiceras*). Instead, chalk and non-detritic limestone start and initiate a new chemical cycle of sedimentation, becoming more pronounced in the succeeding Cenomanian and pointing to a continental slope environment.

In our discusion on the Infracretaceous we have already referred to the anomalies in sedimentation and thickness encountered at the Debora wildcat. Volcanic lavas and tuffs of Jurassic and "Neocomian" age occur in lieu of sediments, reducing the marine Lower Cretaceous beds here to 550 m thickness.

Summarizing the lithofacies provinces of the Lower Cretaceous of Israel one arrives at the following division (see Figure 6):

1. The *limy* pelagic *Carmel* facies.

2. The *sandy-marly-limy* shelf facies of the *Shephela Coastal Plains* (and Judean hinterland), turning to pelagic in the Albian.
3. The *marly*, less sandy and less limy littoral-to-shelf facies of *Galilee*, again more pelagic in the Albian.
4. The *sandy*, less marly and less limy semi-marine facies of the *Northern Negev*; a littoral greensand sub-facies characterizes the Albian.
5. The *continental sandy* facies of *Jordan* and the southernmost Negev, also represented in the lower pre-Aptian section of Eastern Galilee and Eastern Samaria.
6. Pre–Barremian submarine *volcanism* of Western Galilee and the Coastal region from *Carmel to Sharon*.
7. Pre–Aptian continental volcanism of *Eastern Galilee and Eastern Samaria*.

Oil and shows in the Lower Cretaceous

We have already drawn attention to the "shows" par excellence in the Jurassic of Motza, Zohar, Debora, Carmel and Caesarea, in contrast to the lack of "shows" in the Lower Cretaceous of these wells in spite of good reservoir beds. Yet most of the other deep wells which tested the Lower Cretaceous and are situated near the Heletz field or at some distance north, south or east of it, such as Halutza, Rekhme, Sdot Akiba, Safit, Hulda, Revaha, King David, Tlamim, Negba, Gan Yavne and Petah Tikva, were equally devoid of showings (unless one regards the H_2S occurrence found in the Aptian sands of Gan Yavne as indicative).

Our Lower Cretaceous "shows" are then restricted to the few wells drilled in the Jordan and Dead Sea valley, all casually connected with graben tectonics. They displayed viscous and fluid impregnations either in the sands of the Aptian of Massada and Engedi, in the Albian greensands of Engedi, or in the Nubian sandstone of Mazal. Interestingly enough, the Barremian sands of Massada were free of shows.

The wildcat Jordan, near Tiberias, had a good semi-fluid show in a sand layer of the Upper Aptian (above the Blanche falaise) and also, though less indicative, brown stains in fractured Albian limestone.

Heletz field derives its oil from sands referred as "Heletz sands" to the Barremian. Vertical migration from the Infracretaceous black shales as possible source beds was first raised in the discussion on the origin of the oil pool. However, the great number of dry holes with a complete absence of "shows" in the Lower Cretaceous, in spite of black shale formations underneath, weaken this hypothesis. The writer by far favours the explanation of lateral migration for the genesis of the Heletz field, all the more so as the Jurassic test of Heletz 22 was negative, except for an extremely poor show of "spots of asphalt" in the middle section.

The dry wells northeast, southwest and east of the Heletz–Brur field speak against migration from this direction—even admitting that some wells may be off-structure. The probable source area may well be sought in the West, i.e. in the Neogene Ashkelon trough from which oil was spilled and trapped at Heletz.

Cenomanian–Turonian

Except for the Young Tertiary–Quaternary of the coastal plains, of the intermountain depressions and of the Jordan rift-valley, some 75% of Israel's outcropping formations belong to the Upper Cretaceous.

Whereas the Triassic, Jurassic and Lower Cretaceous appear in a few anticlinal erosion openings in the Negev and in Judea–Samaria or at the foot of the uplifted fault blocks of Galilee, more than half of the exposed mountain formations belong to the marine Cenomanian–Turonian.

The Cenomanian and Turonian (attaining thicknesses up to 800 m) built up the top and/or the flanks of all the principal—mostly asymmetric—anticlinal ranges in the prominent mountain bodies of the Northern Negev, of Judea–Samaria, of Carmel and of Galilee. But many of the shallow minor and more symmetrical anticlines also expose Cenomanian–Turonian in the apex or are covered with thin Senonian chalk, e.g. shallow folds on the flank of the Rumman upwarp (Nafkh el Ein), in the Jerafi downwarp (around Taqiya, Qureiq and Ras el Jeib) and near Ain Hashofet in the Megiddo synclinorium. There remain then only the western foothills, the large-sized Jebel Quarn anticline near the Egyptian border and some shallow undulations in the Beersheba–Lachish district which still possess a cover of Eocene.

One can, thus, hardly expect oil-bearing strata in the unprotected Cenomanian mantle of Israel's anticlines, consisting of prevalent calcareous and dolomitic rocks, as manifested in the rough and rocky karstic landscape so characteristic of Mediterranean terrains. These cavernous, highly porous rocks, however, play an important rôle as main producers in the ground water exploration of the country. The largest springs in the country (Yarkon, Kurdaneh, Rosh Hamabua, Engedi, Feshkha, Faria, Tiberias, Malaha, Yahula) are fed from these reservoirs. On the other hand, these rocks form a great obstacle to our petroleum drilling as principal lose-of-circulation zones.

"Shows" in the Cenomanian–Turonian are observed in the graben-fault region at the western rim of the Dead Sea, where asphalt seepages have been known for some time from the dolomite outcrops of Massada and Boqeq (Umm Baghaq). Moreover, asphalt and oil impregnations, as well as gas, were recently detected in the wildcats of Engedi, Massada and Mazal. Asphalt is recorded as occurring in a thin sandbed at the base of the Turonian drilled in the water well of Dewir, NW of Beersheba.

Gas in the Beeri (near Gaza) structure-holes, "issuing from a Cenomanian reservoir", can only derive from the Sakia (Neogene) by migration (Tschopp & Wiener, p. 32). Sulphur associated with gypsum is seen in fault-fissures of Turonian–Cenomanian rocks at the Meliha anticline (Southern Negev).

Drawing of an isopach picture for the Cenomanian–Turonian meets with difficulties, mainly because in the wildcats the boundary beds to the Albian were drilled "blind"; moreover frequently no sharp lithological separation can be made between Albian and Cenomanian. In some wells post-Cretaceous erosion had removed Turonian and/or part of the Cenomanian. Heletz again displays an impressive example: Neogene resting on Mid-Cenomanian, the "biggest unconformity known in the Middle East" (Wellings 1954). But this unconformity is still bigger in Heletz No. 23 (see our discussion in the section on Neogene).

We find, nonetheless, approximate thickness figures which in Southern Israel and Jordan reveal an increasing thickness of marine Cenomanian–Turonian from E to W and SE to NW, according to the following profiles :

1. Wadi Hasi (Transjordan)–Boqeq, 250 to 300 m.
2. Sinaf–Ramon–Mazal, about 400 m.
3. Khabra–Rekhme–Zohar–Engedi, about 500 m.
4. Beeri–King David–Revaha–Jerusalem, 600 to 700 m.

No such thickness profiles could be arranged for Northern Israel. Thickness figures there are, in general, higher, attaining 900 m in the Hermon (Renouard). Carmel and Tiberias both show 800 m; Menara in the northeasternmost Galilee, 785 m (which according to Rosenberg includes Vraconnian); Kamana in central Galilee, 700 m (Golani); Debora near Tabor has the lowest figure of 580 m.

As pointed out previously (1956) and recently elaborated through the fieldwork of Kashai, Karcz and Freund, the Cenomanian and, still more, the Turonian of the Carmel and western Galilee are distinguished by frequent facies changes of impressive riff—thick chalk and marl formations, the depositional conditions of which we had compared to "island arcs near shelf slopes" and to "irregular bottom relief" (1958, p. 22). It would further point to tectonic instability and thus explain the manifold interspersion of submarine volcanics met with in the Carmel (and the Umm-el-Fahm Mountain) in various horizons from the Cenomanian up to the Senonian (Kashai). Within Israel territory the Carmel in Cretaceous time, as noticed in previous periods, apparently belonged to that oceanic section least influenced by shelf and littoral deposition.

Concerning the thickness anomaly at Debora we have as yet no better hypothesis to offer than the influence of a buried magmatic ridge already felt in the Lower Cretaceous.

Senonian (and Paleocene)

The surface distribution of the Senonian is in the main attached to the structural areas of synclines or synclinorial downwarps. Senonian outcropping in the major anticlines forms, with the resistant Campano–Maestrichtian chert, steep hogbacks on their asymmetrical flanks.

The greatest thickness of Senonian, with over 350 m, was measured in the synclinorial depression of the Judean Desert, and recently reaffirmed by the Engedi drill-test.

Round figures of 250 m were found in the downwarps of the desert of Zin (Fuqra) and of Paran (Jerafi), in the Shephela foothills of Hulda, and in the uplifted basins of Megiddo and Safed. The foothills of Lachish (Beth Jibrin) down to near Heletz reveal about 150 m. Lower figures of 100 m or less are displayed by the Senonian–Paleocene beds of the northern coastal region (Caesarea, Kurdaneh, Hanita) and (again!) of the Debora–Tabor area, all situated on or near anticlinal bends.

Considering further the unrivalled high figure of 900 m thickness given by Renouard for the Senonian–Paleocene of the southern Bekaa depression in adjoining Syria–Lebanon, one can hardly avoid the conclusion that the present regions of structural downwarps were in Senonian–Paleocene time maxima of marine sedimentary accumulations. Thus, the thickness relationship which we recognized in the marine Jurassic and Lower Cretaceous as progressively increasing from East (Jordan) to West (Mediterranean) slowly changes in the Albian–Cenomanian. A new thickness pattern develops, which in the Senonian leads to distinct sedimentary maxima and minima.

The phenomenon was ascribed to initial fold orogeny in the Upper Cretaceous. As an alternative interpretation the writer prefers a fault-conditioned swell and basin relief of the sea bottom (the forerunner of the regional up- and down-warp structures) whereby the submarine ridges rarely emerged above sea level.

In other words, vertical movements (the "block-foldings" of Tromp and Henson) were the primary cause of thickness and facies change in a sea covering not only most of Israel but also large parts of Transjordan, thus pushing the continental "Nubian sand" regime even farther back to the Arabian hinterland (Jebel Tuweiq) than did the previous Cenomanian–Turonian transgression.

In the pros and cons of an assumed Senonian orogeny on a regional style, several observations have to be considered. There is a lack of an over-all unconformity and of a regional distribution of base conglomerates or other terrigenous deposits, both at the Turonian/Senonian and Senonian–Paleocene–Eocene boundary. In the thicker sediment accumulations boundaries are not discernible without micropaleontological help.

The Senonian is lithologically built of chalk, chalky limestone, marly chalk and (in the Paleocene) also marl. The chalk is considered a genuine petroleum-source rock, with up to 22% organic matter, over 4% (in S_2) soluble bitumen, and brown transparent bodies around the shell of microforams (Picard 1932, 1954) (exposed to air the dark chalk becomes light grey and only the flint and silicified phosphatic limestone of the Upper Senonian remains blackish coloured).

Among the wildcat "shows" only the Engedi log (I.A.C.) records asphalt "droplets" in fissures of flint and asphalt in "slickenslides" of hard shales.

Eocene

The surface occurrence of the Eocene is still more associated with the downwarp regions. The anticlinal ridges of the Cenomanian–Turonian and their associated asymmetric flanks are practically devoid of Eocene. Eocene extends widely west of the Ramon and Kurnub–Dimona ranges in the structural depressions which start from the Abda plateau down to Nitzana (Auja–Hafir)–Revivim (Khalasa)–Beer-Sheba. From here it occupies the western foothills up to Hulda. Eocene then again extensively covers the downwarped fold-region of Paran (Jerafi) and Igfi in the south-eastern Negev.

The folds of these synclinorial regions (and this also applies to those of the North) are usually smaller, shallower, more symmetrical and frequently of the brachyanticline type. Undulations of this kind are developed in the now-uplifted high plateaux of Transjordan.

In Samaria the exposed Eocene is distributed between Ebal–Garizim and the Um-al-Fahm range and in Ephraim proper between Um-al-Fahm and Carmel. A large area of Eocene is analogously situated, though disturbed by the faulted Kishon valley between Carmel and south-western Galilee (Shefaram to Nazareth).

In spite of the strong block-faulting which has dissected Galilee in the Pleistocene and in spite of an extended basalt and Neogene cover, one is able to follow up the Eocene on the south-eastern flanks of the Galilean upwarp. On the western flank of this upwarp, parallel to the Senonian–Paleocene sedimentary girdle, Eocene appears in sporadic outcrops, intimating that its major portion lies hidden below the coastal plain and sea.

The Eocene in the foothill region of the Negev and Judea, of western Galilee and of Ephraim, consists primarily of chalk interspersed with flint and chalky marl. It frequently resembles the Senonian in lithology and is thus marked by a common egg-shaped smooth hill-morphology. Like the Senonian, the Eocene chalk is occasionally bituminous and may thus be added to the potential source rocks.

Harder limestones in the higher Negev (Abda plateau) and in the Sinai produce an esplanade landscape with enormous regional plateaux and cuestae. In the lower Eocene table landscape of Edom–Moab there is—as in the Senonian—interstratification of phosphatic limestone.

Harder limestone and marble limestone of uppermost Lower to Middle Eocene age are widely found in central and eastern Galilee, evolving a pronounced rough-hewn karst landscape which contrasts greatly with the smoother relief forms of the foothill regions of Israel. Some of Galilee's bigger springs derive from the Eocene karst (Gilboa, Migdal, Wadi Amud, Tabgha, Daishun, Kfar Giladi).

Upper Eocene is limited to the coastal plains and foothills, which include the Ephraim and Shefaram hill-land.

Episodic transgression and regression, but with a general tendency to a westward retreat of the sea from the Lower to the Upper Eocene, is noticed. Thus, the Lower Eocene is found in most Eocene sections of Israel. It is the principal Eocene formation in Jordan, whereas Middle Eocene Lutetian is practically absent. Rather inferior in thickness in Nazareth and Hanita, Middle Eocene is largely developed in the sedimentary troughs of Ebal-Gilboa and southeastern Galilee (several hundred metres thick) and in the Saliha-Bent Jebail (north Israel–Lebanese Galilee) syncline. It again attains a maximum thickness in the southern Beka'a (850 m of Lutetian limestone). Upper Eocene is absent in these regions. Disconformities (termed generally discordances) separating Eocene from Upper Cretaceous, as well as breccious or conglomeratic interstrata, still deposited in a marine milieu, have been observed more and more. They were discussed quite early in the literature on Egypt and Sinai (Hume, Beadnell, Cuvillier). Isolated sedimentary breaks were recorded by Blake in Northern Israel (1936, Tulkarem, Jebel Sih); they first became known in the Negev of Ramon by the I.P.C.'s geological work (Shaw 1947, p. 31), recently supplemented by the Israel Geological Survey (see Ball). With the end of the Lutetian the mountain body of Israel was standing above the sea and—except for minor ingressions in the Neogene—has remained continent ever since. The foothills and coastal regions, however, still remained below sea level in the Upper Eocene (and some parts also in the Oligocene).

It is in the Shefaram hill-land (Rabinovitch) that we find from the Lower to Upper Eocene a rather complete, often uniform and very thick sedimentary accumulation (600 m at Megiddo, 1500 m at Shefaram), becoming reduced in the foothills from Hulda to Beersheba to an average thickness of 250 m to 300 m (compare Figure 1 with Figure 2). The same medium thickness (300 m) is also noted in the recent Hedera well (G. Olga), although this was drilled in what is thought to be the continuation of the Ephraim Eocene synclinal basin. In the new Gaash wells (15 km to the south) the Eocene is apparently absent or, if present, is of insignificant vertical extension.

Relatively low thicknesses of 145 m to 160 m (including Paleocene) in the wildcats around the Heletz field may be the result of later erosion, which would explain the absence of Upper Eocene and part of Middle Eocene in Revaha, Tlamim and Beeri. The well-log of Ziqim, however, revealed a 165 m thick succession from Paleocene to Upper Eocene (with possibly 91 m of Oligocene above).

On the other hand, at Gan Yavne Eocene is completely missing; Oligocene rests on Turonian. At Negba 27 m of Eocene lies on Cenomanian. To this list we add the aforementioned hiatus betwee Cenomanian and Neogene in Heletz-Brur. Thus one arrives at the conclusion that uplifts during pre-Eocene and pre- and post-Oligocene, followed by erosion, took place in the area north, south and east of Heletz.

Surface indications of asphaltic joints and veins are especially rich in the chalk and flint of the Megiddo-Shefaram synclinoria, where faulting has freed the viscous bitumen.

None of the wildcats record hydrocarbon shows in the Eocene.

Oligocene

The Oligocene is restricted to the area of Upper Eocene distribution, i.e. the foothills and coastal plains.

The few outcrops in Ephraim (near Ramat Hashofet), Ramleh and Lachish (Beth Jibrin) reveal detrital and conglomeratic shore, but also shelf, limestone and chalk facies.

At Ephraim 30 m (Arad) and at Lachish 50 m (Golik, Greizer) in thickness, the Oligocene is unconformably cut by Miocene.

A lithological resemblance of the Oligocene to the Upper Eocene or basal Miocene has left many an age determination still uncertain.

Thus, the Mafqiim log records bottom strata of limestone, chalk and oil-impregnated marl of uncertain Oligocene–Miocene age. The Ziqim log gives 91 m of hard shales and marls as "Oligocene (?)". Any Oligocene of important thickness thus must be searched for in the depths of the present Mediterranean shelf.

Coastal Neogene

Israel's major rise out of the Tethys in the Upper Eocene continued in the Oligocene until, at the end of the Oligocene or earliest Miocene, foothills and coastal plains also emerged. Finally, the anticlinal-synclinal fold pattern evolved at a last stage in the middle Tertiary, well manifested in Miocene-Vindobonnian transgressive sediments cutting—wherever exposed—with sharp angular (abrasion) discordance the folded Tertiary and Cretaceous rocks. As in the Oligocene-Upper Eocene the foot hill region was again flooded in the Mio-Pliocene. But now, fault-conditioned transversal embayments enabled the sea, in the succeeding episode of Vindobonnian and Astian-Plaisancian, to enter through the mountain body into the Esdraelon and Beersheba depressions, thereby containing the contemporaneous contacting inland lakes and rivers.

The sporadic outcrops of marine Miocene (Haifa Bay, Ephraim hills, Lachish, Beersheba) consist of coarse-grained and coralligenous limestone, of shore sands, of lagoonary, and occasionally of gypsiferous marly sands. This littoral complex is

of inferior thickness (average 50 m). Westwards, with increasing thickness, the sediments become more silty-marly, known as the Sakia formation, principally of Pliocene age. They are followed below by marls and chalks which in deeper layers turn into consolidated shales, principally of Miocene age. There are still some difficulties in distinguishing Miocene from Pliocene in the cuttings of the coastal wildcats; the logs usually indicate Neogene or, in a broader sense, Sakia.

The "Sakia" (s. l.) contain only rare (and then very thin) sandstone intercalations and, still more rarely, sand lenses.

Below the Quaternary (average 80 m thick) and topping the Sakia formation the beds are conglomeratic (Astian) or sandy, occasionally with fine gypsum flakes. In the Miocene bottom section of Beeri, Gan Yavne and Mafqiim we met with 78 m thick properly bedded and brecciated gypsum mixed with shales, chalk and limestone. Outbursts of methane gas occurred in this bottom section. The sour gas of Beeri (99% methane) found in the Turonian derived, in the opinion of Tschopp and Wiener, from the Neogene. Moreover, in the same lower section of Mafqiim (N.I.P.), the only impressive show of "oil-soaked clay" was discovered. Slighter gas shows were registered in some higher beds, especially in the aforementioned sandy top-strata close to the Pleistocene base (Gaash, Petah-Tikva, Caesarea slim-hole, Kiryat Hayim water well). The 675 m well of Gaash recorded no less than 16 slight "showings" in the gas detector in Sakia beds between the 100 and 550 m depth; thin interbeddings of sandstone were remarkably free of gas shows.

Great thicknesses of drilled Neogene are found near the coast, such as: Beeri, 600 m; Hadera, Gaash and Gan Yavne, about 700 m; and above all, west of Heletz, Mafqiim with 1300 m and Zikim with 1700 m. The western well of Heletz, No. 23, still has 700 m, but this decreases rapidly to the east, with 200 m at Heletz No. 1 and zero at King David. At Beeri there is a thickness decrease in a reverse direction from 600 m in the east to 450 m in the west.

The thicknesses in the slim-holes of Caesarea vary similarly in different directions: SE 400 m, NE 200 m, SW 115 m, W 20 m. Tschopp-Wiener explain this phenomenon at Beeri as the effect of erosion channels. Grader follows this concept for Heletz and speaks of karstic erosion channels of a magnitude of hundreds of metres, according to his isopach and gravity maps (1958, Figures 4 and 5).

The writer believes that it is better to explain this phenomenon of short-distance changes of thickness in different directions, together with the manifold formational lacunas (e.g. Sakia resting on Cenomanian at Heletz and Brur, Sakia or Oligocene on 85 m of Turonian at Beeri, Sakia on 36 m of Turonian at Gan Yavne, Sakia on 25 m of Eocene at Negba, Sakia on 125 m of Lower to Mid-Eocene at Sdot Akiba, Sakia on Oligocene and/or Upper Eocene at Ziqim and Mafqiim, and a complete absence of Sakia at Tlamim and King David), by the assumption of

block structures with varying tiltings which built the pre-Neogene buried ridges of Heletz-Beeri (and possibly also of Caesarea). In his Report to the Government (April 1956) the writer compared the "Heletz hinterland in Neogene time to a land mountain similar to the Carmel of today". In other words, he considered Heletz a horst or half-horst, the steep western flank of which borders the "Ashkelon trough". The character of the Neogene found in the deep-tests of Mafqiim, Ziqim and Gan Yavne of the Ashkelon trough clearly demonstrates their great affinities with the other Neogene basin fillings of Northern Syria (Alexandretta) and of the Suez-Red Sea graben. The extension of the Ashkelon trough may have been of no less regional size than the Suez basin (if not larger), and the sedimentary cycle of related nature. The bedded gypsum in the lower beds of Mafqiim referred to base Miocene shows the lagoonary stage of an occasionally closed basin so common in the Neogene of the Suez graben as well as in the eastern and western Mediterranean Miocene basins (the gessoso-solfifera formation in Italian literature; see also Picard 1928 and extended discussion in 1943, p. 43 ff, Figures 11 to 14).

The great amount of material accumulated since our 1956 report, due to the intensive drilling in and around the Heletz field, has now been worked up and published by Tschopp, Wiener and Grader. It has strengthened the writer's concept of regarding the Heletz structure as a tilted *block* mountain flanking the Neogene graben of Ashkelon, as illustrated somewhat diagrammatically by Figure 8.

As in the Carmel horst or half-horst, the internal structure of Heletz before the early Miocene fault destruction might have been an anticlinal fold (stronger dips may in this case be ascribed to asymmetrical bending, but can also be interpreted as later fault drags).

The eastern Carmel hinterland, the prevalent Eocene synclinorium of Ephraim (Megiddo), may then be compared with the Eocene Heletz hinterland and foothill region of Lachish.

The postulated erosion channels may well be the result of differential rock-type erosion of soft chalk and hard limestone leading to cuesta morphology soon after faulting in early Miocene and before the graben was filled up with Pliocene sediments and the Heletz mountain had submerged in Upper Sakia time below sea level.

Whereas Heletz became thus a buried ridge, covered furthermore by the coastal Pleistocene, the Carmel and Megiddo hinterland, similarly flooded by the Miocene sea (if not wholly, then in part), was uplifted in early Pleistocene along the reactivated major Neogene Kishon fault).

Most of the Miocene has since been removed from the mountains by atmospheric erosion, but some relics have remained up to 400 m high both in the Carmel and in Ephraim.

The Heletz promontory, however, was not (or not sufficiently) uplifted by Pleistocene fault movements, which were, indeed, less accentuated in southwestern Israel. Thus, a proper Neogene cover has remained over the Ashkelon trough and over part of the Heletz buried mountain, a cover which must have been even thicker before marine Pleistocene or fluviatile gravelling levelled the Neogene surface.

In analogy with the Suez Gulf conditions, oil is thought to have moved either from the Neogene-Oligocene source beds, of which the oil-soaked clay of Mafqiim is a good example, or from the bituminous Eocene-Senonian chalk underneath (over 250 m thickness at Ziqim). Lateral migration from the graben block (or blocks) or from the Neogene overlap into the border horst is believed to have taken place along bedding and fault planes at some stage of Miocene faulting. It drained the Oligo-Eocene source beds of the Ashkelon basin, but it may as well have drained the Neogene source beds themselves during some later stages of subsidence (Plio-Pleistocene) when sagging and sediment compaction of the Neogene occurred.

In fact, Tschopp presumes lateral migration from the Sakia formation for the Turonian gas of Beeri, but adheres (1956, p. 50) to vertical ascent of the Heletz oil from Jurassic-Infracretaceous source beds into the "anticlinal crest". Although for this process he favours the Senonian as the "climax of folding", there are in his opinion "some indications that uplifting movements took place at the verge of Jurassic to Cretaceous times which might have created satisfactory traps". Moreover he also assumes "posterior folding phases in the Eocene and in the interval from the Oligocene to early Miocene" (our former Burdigalian orogeny), during which "drainage of oil-accumulation continued". As these folding phases were considered to be separated from each other by subaerial "erosional phases," the question arises why after so many repeated tangential stresses the Cretaceous and Lower Tertiary rocks are still in an unmetamorphous state. Or is our concept of 1954 more likely, namely, that further epeirogenic up-and-down movements took place in Senonian-Eocene times, rarely lifting the submarine ridges above sea level, while the proper tangential push occurred later between the Oligocene and Miocene (1943 and 1958, p. 22)?

In our view the oil migration and accumulation of the Heletz field is a horst-graben phenomenon associated principally with early Miocene major faulting, though the migration of hydrocarbons—especially gas migration—might have continued up to Recent times (sulphur plus bitumen impregnations in the Pleistocene-hardened Kurkar dunes of Beeri). Many a fault-block hidden in the shelf and some (though possibly only small ones) in the coastal plain may possess oil-prospecting conditions similar to Heletz. Endemic folding in the Levantian Neogene basin, of which the Ashkelon trough forms only a part, may have taken place in the more central section due to the tectonics of larger bodies of evaporites (gyp-

sum, salt?) but mainly due to space shortening of the graben. The Proto-Pleistocene downbreak of the eastern Mediterranean and its transformation into the present archipelago and its surrounding deep-sea gräben has (unfortunately) left on our coast a very short shelf for future off-shore exploration.

The size of the Ashkelon trough is unknown but, judging from the isogam map of de Bruyn (see Figure 9), it belongs to an area of pronounced negative anomaly. The same order of minima continues over the Nile delta and the Suez Gulf, suggesting a *negative gravity* unit for all three regions. The map, furthermore, reveals an E–W isthmus of positive anomaly which extends to the Levant mainland, thus separating the Ashkelon–Nile delta–Suez basin from the Cyprus–Alexandretta trough.

Continental Neogene

Finally, we have to consider the prospecting value of our Neogene and Quaternary inter-mountain troughs and Jordan graben, occupied principally by continental formations.

Our continental Neogene rests—like the contemporaneous marine Mio–Pliocene—discordantly upon all the pre-Miocene formations, frequently starting with base conglomerates (Kfar Gileadi, Tiberias, ed Dra'a, Sdom(?), Dimona, etc.) and/or sandstone (Engedi, Sdom).

In the *North,* in the Emek and Eastern Galilee, the continental Neogene represents the filling masses of huge fault depressions which extend from the Esdraelon valley to the Jordan valley (between Tiberias and Beth Shean) and from there, possibly, as far east as the foot of the Hermon. In this region of tension, intensive "continental" basalt eruption took place in three main stages; Miocene, Pliocene, Pleistocene. Limnic freshwater limestone and marls, brackish water marls and chalk with bedded gypsum intercalations (the Birah series), and red beds of sands and gravels (the Tiberias series) form the principal sediments, attaining thicknesses of 300 m (Shulman). In the central part of the basin they are underlain (Miocene) and overlain by compact sheet-basalt and tuffs each of 250 m thickness. The Miocene volcanics may be still thicker, the base not being exposed. In adding to the Neogene the Pleistocene deposits also, one arrives, for the Young Tertiary–Quaternary of the central Jordan and central Esdraelon–Tabor valley, at figures exceeding 1000 m in thickness, two-thirds of which are of tight-sealing character. This cover (including thin interdigitations of entirely littoral Pliocene), however, plays no rôle as source-bed material; no indigenous bituminous sediments are known. However, the sealing nature of the cover must have prevented the upward vertical movement of freed bitumen deriving from the underlying Paleocene-Senonian or older source beds. Instead, it must have compelled the bitumen to migrate laterally into the fault border blocks of the Tabor or Tiberias graben during the Pleistocene tafrogeny. It is in this way that we explain the

strong petroleum odour in the upturned gypsum formation of Menahamya and the definite show in the Upper Aptian sand of the Jordan wildcat at the tilted block of Mt. Herod, which is situated on the western rim of the Tiberias-Jordan graben. This interpretation also applies to the impressive "bleeding" of the Jurassic limestone cores and the volcanic material of the Debora well drilled near the fault escarpment of the Tabor graben.

This has strengthened the writer's long-held view, which he had in mind when locating Debora and Jordan 1, that more attention has to be given in the search for oil to the intermountain basins and graben-structures of Galilee, a view also expressed recently by K. Landes.

In the South, in the Negev upland, the continental Neogene east of Beersheba is (like the Palmyra chains of Syria) attached to synclinal valleys (W. Milh, Rekhme, Kurnub).

One might assume for the Neogene of Hatzeva (former Hosb), Sdom and ed-Dra'a (in Transjordan) a related synclinal position before early Pleistocene faulting transformed this region into the Dead Sea graben. However, the enormous thickness and the character of the sediments, which in one locality (Ein Yahab) revealed interstratified volcanics (Shiftan), suggest a graben-sink already existing in the Neogene. The synclinal basin of the Paran (Jerafi) downwarp contains chalk and clay beds of limited thickness and of limnic character. Most basins are rich in gravel and coarse sands continuing partly into the Pleistocene. Age assignment to Neogene and/or Pleistocene is then often difficult. None of these Neogene basins of synclinal position has a filling exceeding 200 m. Moreover, prevalent clastic unconsolidated material excludes this Neogene from forming a valuable seal.

There remain then the so-called "Hosb–Usdum" sediments exposed around the southern Dead Sea and in the northernmost Araba. They were also found in substantial thicknesses in the Engedi wildcat of the I.A.O. and in core-drills around the (Sdom) mountain carried out for the Jordan Exploration Company. It is in this graben section from the Zin (Fuqra) outlet to Engedi and in Transjordan opposite from the Lisan peninsula to the Arnon (W. Mojib) that all the important hydrocarbon "shows" of the extended Jordan-Araba rift valley are concentrated. South of the Arnon there are still active oil springs and ozokerite residuals. North of the peninsula there still occur, from time to time, submarine outflows, giving origin to masses of asphaltite floating on the surface of the Dead Sea.

Quite a number of sulphuric and aluminate springs are found along the shore of the sea. The pre-Neogene showing in the Massada and Engedi wildcat and their relation to the rift border structure have been discussed previously. The Neogene to Quaternary exposures and drillings revealed tar-impregnated sand and gravel resting on the down-sunken Cretaceous fault blocks which are similarly fissured by viscous asphalt. Examples are Wadi Muhauwat and Mazal drill (Turonain to Pleistocene), Tarsand wadi and Engedi (Senonian to Neogene sand-

stone). There is little doubt as to their Pleistocene–Recent age. When, as in the Engedi wildcat or in the core drills around Sdom, good seals of Neogene ("Foothill") or Protopleistocene (Samra) clays were present, the bitumen was prevented from reaching the surface.

The continental Neogene has been divided into the Usdum series and the so-called Foothill series. The Usdum series consists of a 100 m sandy lower part followed by paper shales plus fine-bedded dolomite as the upper part. With the 120 m exposed underlying salt and anhydrite of varying thickness, the Usdum series constitutes the principal mass of the Sdom (Usdum) Mountain. There is still discussion going on concerning the structure of the mountain and the stratigraphic position of the salt and the so-called cap rock (see Picard and Vroman's report to the Jordan Exploration Company, 1947, and Vroman-Bentor 1954). The writer's recent view of the structure and stratigraphy of Mt. Sdom is expressed in the general section (drawn March 1958) shown in Figure 10.

The foothill series, prominently framing the flanks of the Sdom Mountain, was recently found in more outcrops along the shore plains of the Dead Sea and in the drilling sections between Sdom and the Negev mountains. Accordingly, the foothills are about 700 m thick. They consist here dominantly of clay and gypsum beds and thus offer a first-class cover, with clastics at the base. The figure of 700 m was also obtained in the Engedi wildcat. Far higher figures were found in wildcat Sdom No. 2 for a very clastic group of sediments which only somewhat resemble the foothill type. A similar and still greater puzzle is provided by the nearly 250 m thick rock salt complex drilled in Sdom No. 2 at the western foot of the mountain. High angle dips and strata repetition due to faulting, as assumed in our section (Figure 10), are here put forward as an explanation.

The uplifted "Lisan" Pleistocene (of 50 to 100 m thickness), demonstrated by Wyllie (1932) as a proof of the historical movement of the mountain, is in our opinion due to a combination of fault and salt tectonics.

The highly complicated tectonic disturbances brought to the surface the Precambrian on the Transjordan side and squeezed the salt horst of Sdom "comme un hors d'oeuvre au milieu la plaine" (to quote Lartet). In spite of two deep tests and a number of core-holes and geophysical research around Sdom, we have not yet obtained any satisfactory picture of the subsurface structure.

The narrowness of the Dead Sea graben (which prevents the development of larger structural segments), as well as the lack of Neogene marine source beds, certainly reduces its prospecting value as compared with the Suez and Ashkelon troughs.

Quaternary

The "air-covered" Quaternary has, from a petroleum research point of view, mostly been incorporated in the previous chapter. In the coastal plains the Quater-

nary rarely surpasses an average thickness of 80 to 100 m. It consists of basal fan-gravel (Villafranchian) with overlaying calcareous hardened dune sandstone (Kurkar); and sandwiched in between are the weathering products of sandy terra rossa (redsands). The coastal formations are then topped by loam, loess and recent dunes. Marine littoral formations have rarely reached the interior. Their very thin terraces are found only in the region of the Carmel, evidencing the uplift tendency of this mountain from Neogene to Recent. Contrariwise, the coastal depressions remained the region of subsidence, with the youngest ingressive sediments at the present sea level.

Far stronger subsidence is noticed in the Dead Sea–Jordan graben. Tectonic episodic movements are reflected in fluviatile and limnic cycles and further basalt volcanism. Gravel accumulation alternates with late deposits of arid-brackish (Lisan beds) and freshwater character (Melanopsis beds), as today in the Dead Sea and in the Lake Tiberias bottom. The Pleistocene Hula graben is similarly built of interchanging gravel and freshwater chalk in addition to swampy peat layers, the old diluvial age of which is also indicated by an extinct fauna of *Vivipara,* snails and elephants, together with the earliest human implements of Abbevilian type. The thickness of the graben sediments may reach several hundred metres, but here, as in the Neogene, tectonic movements have brought the layers into such a steep position (better recognizable in the more consolidated basal strata of the so-called Melanopsis series) that the true thickness is hardly to be calculated from drill cuttings. Difficulties are often increased by the already mentioned lithological similarities between continental Pliocene and older Pleistocene. Good examples are provided by the Engedi wildcat drilled through 250 m gravel and Lisan beds, as well as through 290 m gravel-marl Samra-foothill (?) beds underneath. The recent core-drill in the northern Hula plain went through 600 m of alternating gravel, silt, marl and clay with basalt intercalations.

For more details on the Pleistocene to Recent shows of asphaltite, tar and petroleum, as mentioned in the former chapter, the reader is again referred to the writer's previous publications (1954, pp. 16–23). This paper also deals with peat gas and the native sulphur of Beeri, near Gaza, which has stimulated the country's search for petroleum for almost the past thirty years.

CONCLUSIONS

The initial phase of oil-drilling operations was begun after the Second World War by the Jordan Exploration Company (a subsidiary of the Palestine Mining Syndicate) at the southern end of the Dead Sea region. It was soon followed by the spudding in of Heletz in the southern coastal plain near Ashkelon, as an exploration well of the Palestine Petroleum Development (a subsidiary of the Iraq Petroleum Company).

The history of Israel's oil-drilling operations is only a few years old. It started in 1954, and over thirty wildcats (deepest 4000 m, average 2000 m) have since been carried out. Apart from the areas just mentioned, the drilling programme (mainly on the recommendations of the Ball and other reports) was directed to the well-exposed anticlinal features with largest closures up to 500 metres.

Notwithstanding the abundant reservoir rocks and good seals, the wells of Debora, Carmel, Motza, Rekhme, Kurnub and Zohar, all located on distinct anticlinal crests, remained "dry" (except for low-pressure gas at Zohar). But apart from the Heletz-Brur pool and some gas wells which have not yet been exploited commercially, the other wildcats of Haifa Bay, Caesarea, Petah Tikva, Hulda, Gan Yavne(?), Tel-Safit, Revaha, Tlamim, Sdot Akiva, Beeri and Halutza were equally "dry", in spite of the fact that at least half of them were located on proven closed structures.

Excellent "shows" (but not yet leading to production) in all formations from Triassic to Recent were encountered in wells drilled on graben structures. These are: Mazal, Massada, Engedi, Jordan (Tiberias), all situated on the border of the Dead Sea–Jordan graben, and Debora, near the Tabor graben. The oil and asphalt shows in these wells were still, like the seepages at the Dead Sea, in a fluid, waxy and viscous "living" state.

To this category may also belong active signs of hydrocarbons displayed in the Haifa Bay and Caesarea wells, both located on the hybrid structures of faulted anticlines.

Finally, we ascribe the producing Heletz-Brur wells and the Saad-Beeri gas findings (again near the Mediterranean coast) to related, but larger-sized, block structures. The writer believes that the Heletz-Brur pools occur in a faulted border structure attached to a Neogene faulted basin, termed the *Ashkelon trough*. Taking into consideration recent regional gravity surveys, he has arrived at the conclusion that the Ashkelon trough belongs to a system of Neogene gräben now partly covered by the Mediterranean. Furthermore he compares the Ashkelon trough with another sector of this system, namely the Suez graben. More lateral than vertical movements of oil are thought to have taken place in Heletz under conditions similar to those in the Suez graben.

Clays soaked with "live" oil occur at Mafqiim in the depths of the graben itself. Moreover, methane gas, mostly under high pressure, is often met in the Neogene fillings of the graben, in the so-called Sakia beds. (Lateral migration of Neogene gas is also made responsible for the gas discovery in the "blocks" of Beeri-Saad). Gas outbursts in the Sakia waterwell and later in the sulphur mines near Gaza (Beeri) led in fact to the first oil exploration in the Philistine plain.

Thus, Israel's coastal and off-shore areas again deserve to be the primary object in future oil explorations. Interest, however, should also be directed to the other graben structures, i.e. Jordan-Dead Sea and Esdraelon-Tabor valley, in spite of

their reduced size and their lack of marine Neogene-Oligocene source material when compared with the Ashkelon trough.

Several wells of the large "dry" anticlines and of faulted-fold structures have revealed good to very good "shows", e.g. gilsonite and asphaltite in the Carmel, asphalt and oil in Judea (Motza), mostly oil and gas in the Judean desert (Zohar) and asphalt veins and oil-bleeding joints at Debora, Caesarea and Beeri.

All the shows occurred in the Jurassic limestone, particularly in its top section. A tight-sealing black shale complex, referred to the Infracretaceous, separates Jurassic limestone and shows from the Lower Cretaceous; the latter formation is remarkably free of shows (notwithstanding many interspersed porous formations).

Thus, all the phenomena speak in favour of former upward movements of oil from pre-Jurassic source beds during a post-Jurassic orogeny. Genuine marine source beds of Triassic or Paleozoic age should be searched for (see lithofacies maps) in the regions of the western Negev and central and northern Israel. Yet here too they mostly lie too deep to justify their testing. Sinaf, the only Paleozoic test (though Kurnub may have touched it), met with predominantly continental "Nubian".

End-Jurrasic upheaval, followed by Early Cretaceous erosion and gravel accumulation or by continental sand deposition, was noticed in eastern Galilee and the eastern Negev. But, in the western Negev and central and northern Israel, i.e. in the regions of asphalt-impregnated Jurassic limestone lacunae, disconformities and unconformities are unknown. The Jurassic limestone passes here with interwoven black shales into the shale complex. Nor do real indications of major fold movements appear in the Lower Cretaceous of these regions.

Thus, folding, oil movement and trapping in fractured Jurassic limestone must have taken place after the Lower Cretaceous, i.e. at a time when the present anticlinal-synclinal pattern of the country evolved. As to the exact age of this orogeny, opinion varies between Upper Cretaceous and Lower Mid-Tertiary.

Among the wildcat anticlines with impressive shows in the Jurassic, the Zohar wildcat revealed many peculiarities: (1) fewer asphaltic (as against more fluid) oil-shows in dolomite as well as in sandstone are distributed in the Upper, Middle and Lower Jurassic beds; (2) substantial occurrences of methane (with 650,000 cu ft production capacity, according to Winter); (3) the facies of the Jurassic was most similar to that of Massada, but very distinct from Rekhme and Kurnub, although Rekhme, Kurnub and Zohar belong structurally to the same anticlinal range system.

In view of the proximity of the Dead Sea graben, the question may arise whether oil and/or gas have moved from the dislocated graben zone and migrated as far (9 miles) and as high (3000 feet difference in altitude) as Zohar. Such a movement would also help to explain the unusual accumulation of gas at Zohar, which was absent in the other tested anticlines, but occurred frequently in wells placed on structures belonging to the gräben of the Dead Sea and Ashkelon.

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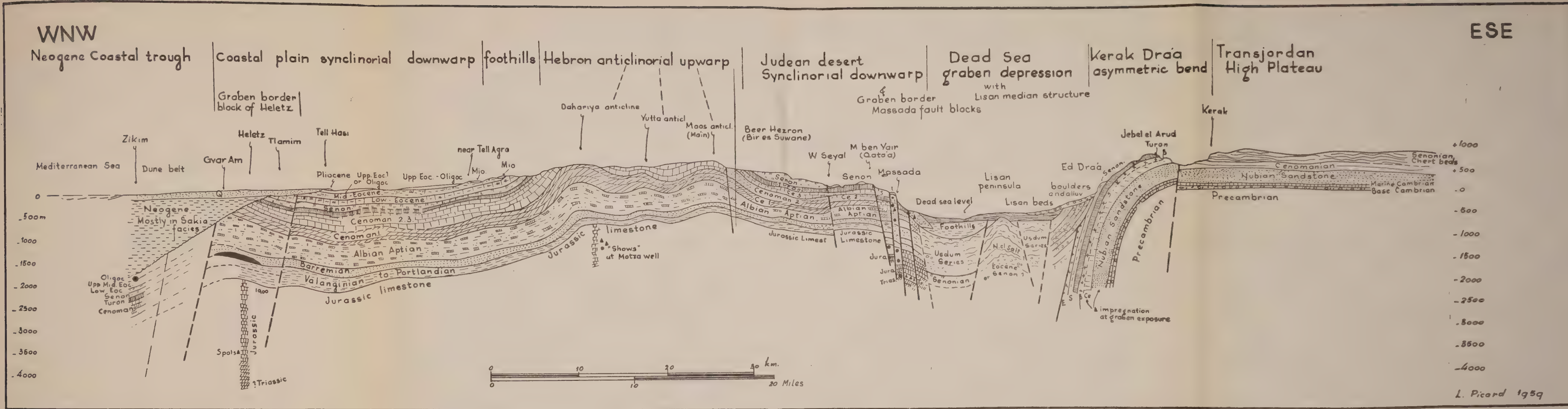
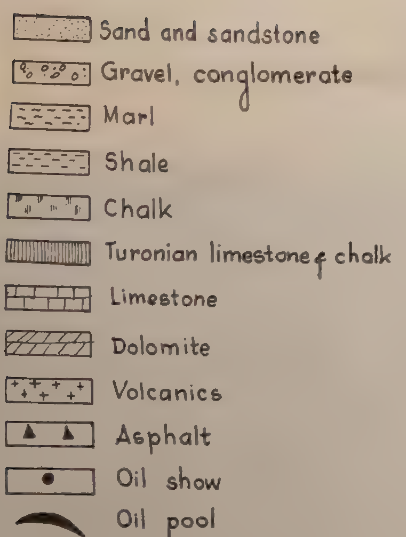
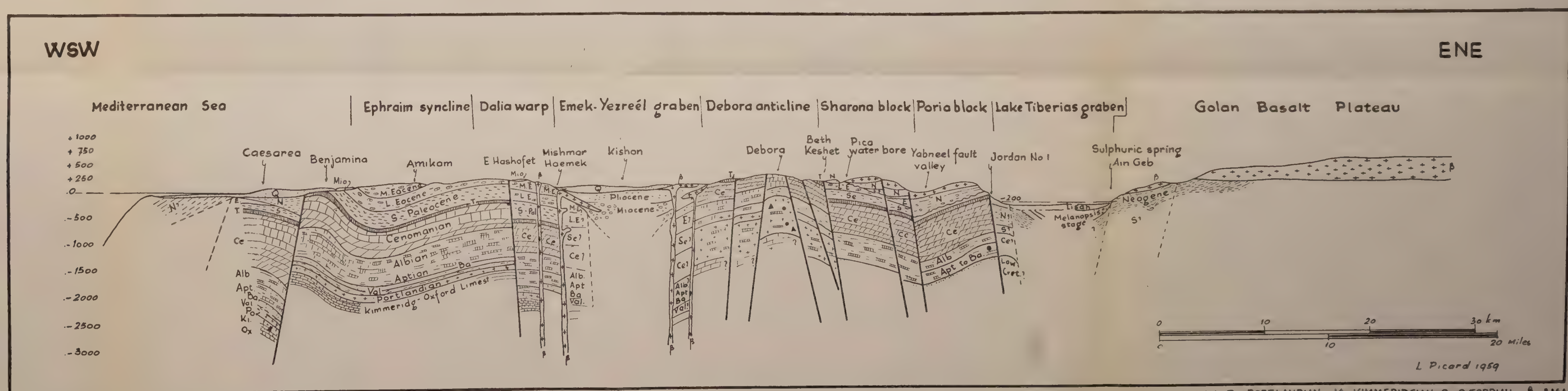


Figure 1
Cross-section: Mediterranean near Ashkelon to Dead Sea, Transjordan (near Kerak)





Q - QUATERNARY N - NEOGENE Mio - MIOCENE E - EOCENE M.E - MID-EOCENE L.E - LOW-EOCENE S-Pal - SENONIAN-PALEOCENE T - TURONIAN Ce - CENOMANIAN Alb - ALBIAN Apt - APTIAN Ba - BARREMIAN Val - VALANGINIAN Po - PORTLANDIAN Ki - KIMMERIDGIAN Ox - OXFORDIAN β - BASALT

Figure 2
Cross-section: Mediterranean at Caesarea to Lake Tiberias, Syria (near Ein Geb)

Q = Quaternary
N = Neogene
Ol. = Oligocene
tu. = Turonian
Ce = Cenomanian
L.C. = Lower Cret.
J. = Jurassic
Tr. = Triassic
N.S. = Pre-Triassic
- Nubian Sandstone
▲ = Asphalt
● = Oil
♂ = Methan gas
× = Odour
♂= H_2s Gas
◯ = Oil fields
of Heeltz

Figure 3
Map of oil, hydrocarbons and other shows

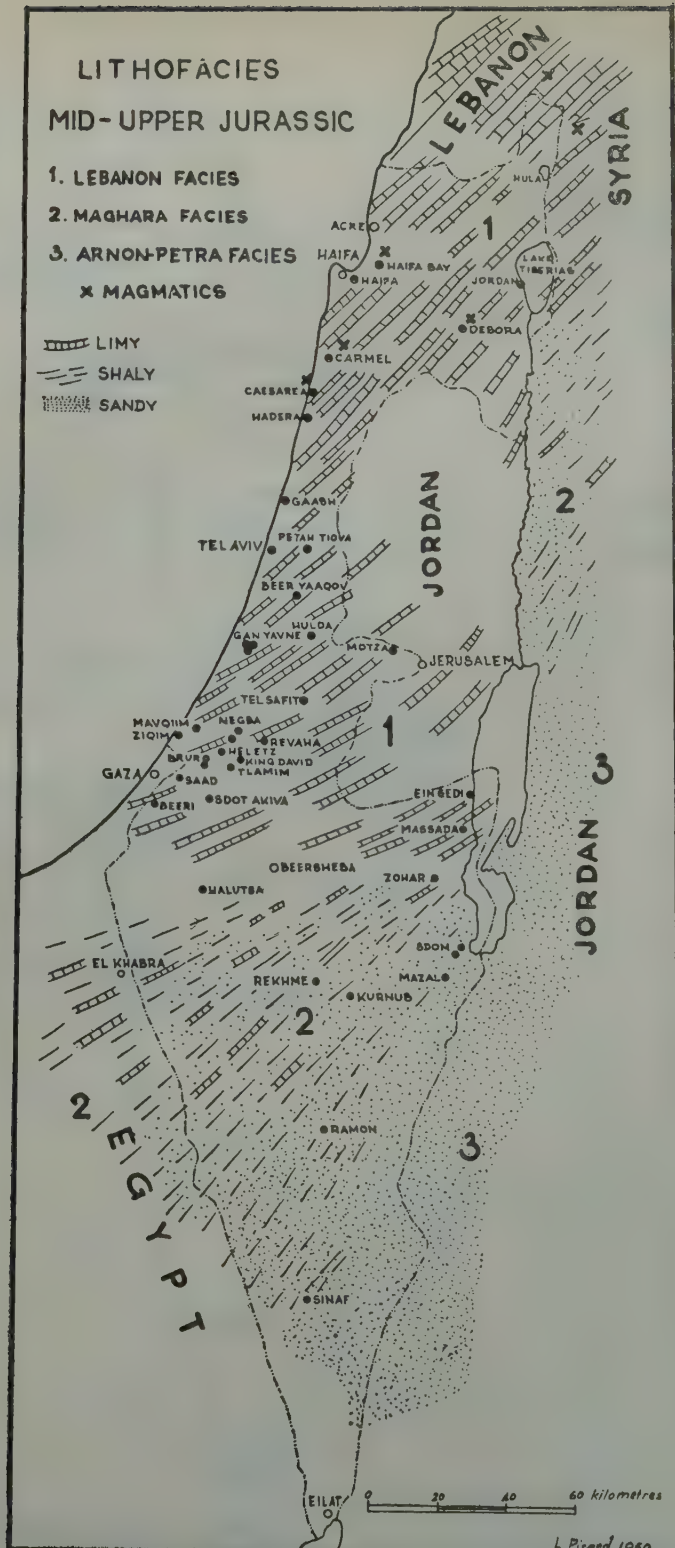


Fig. 4.
Lithofacies map of Mid–Upper Jurassic

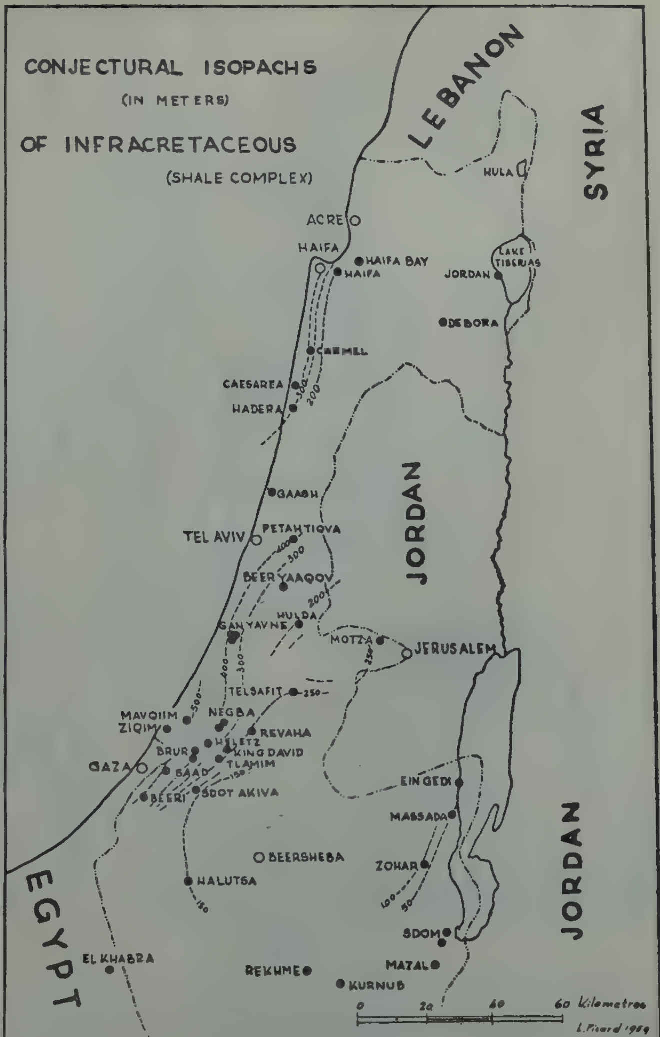


Fig. 5

Isopach map (conjectural) of Infracretaceous (shale complex)

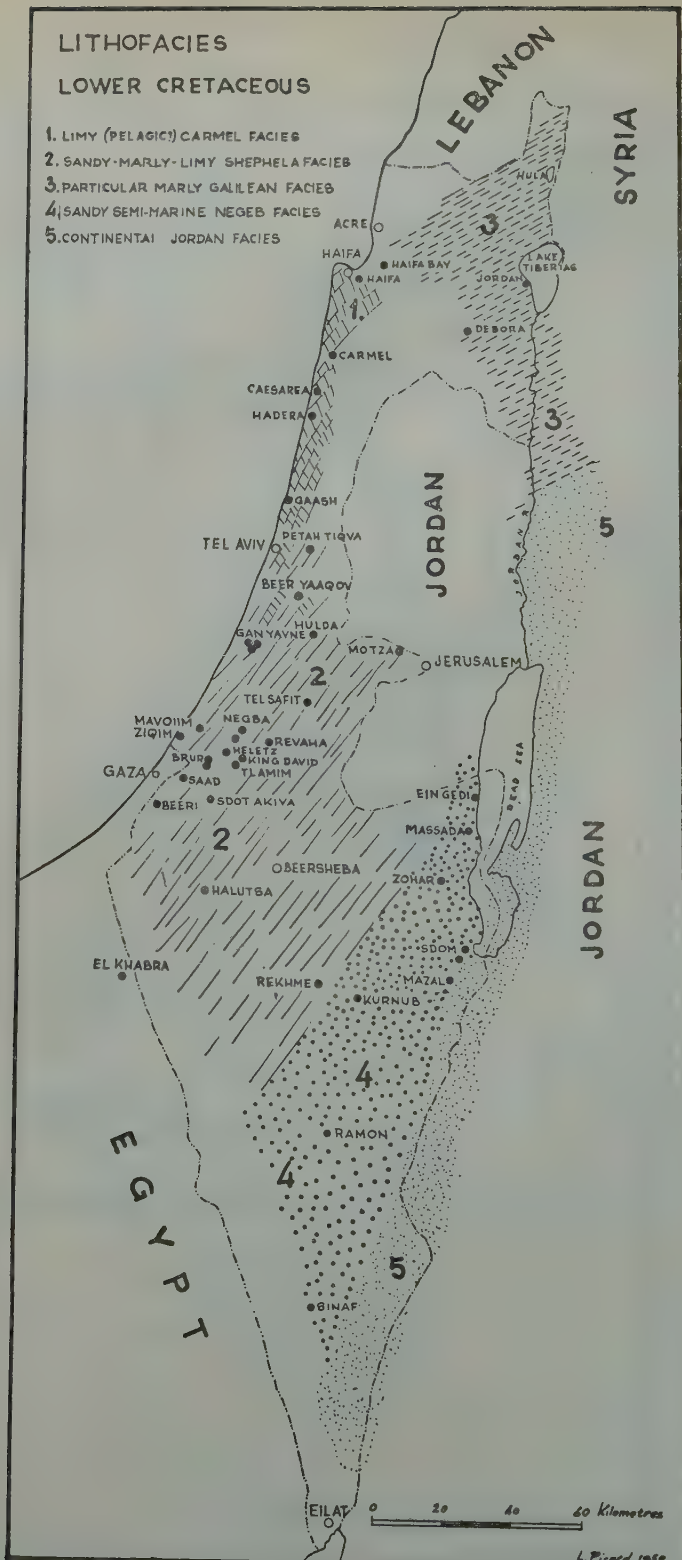


Fig 6.

Lithofacies map of Lower Cretaceous

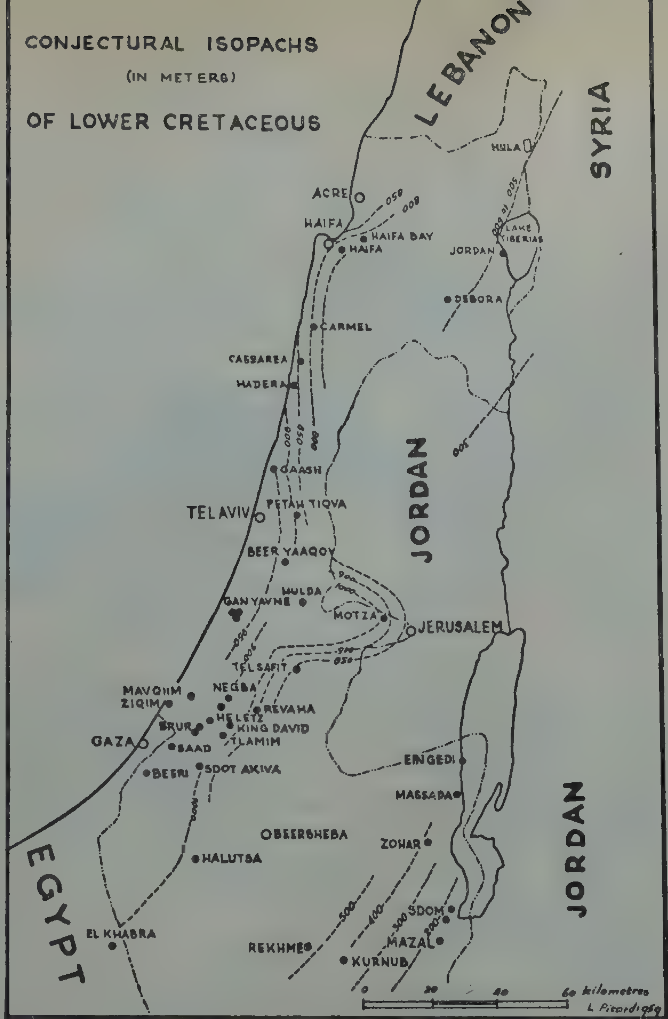


Fig. 7

Isopach map (conjectural) of Lower Cretaceous

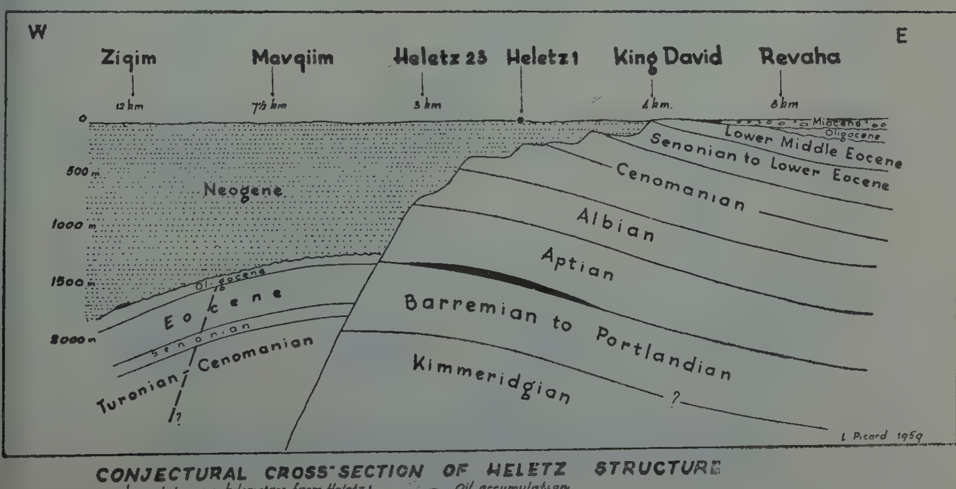
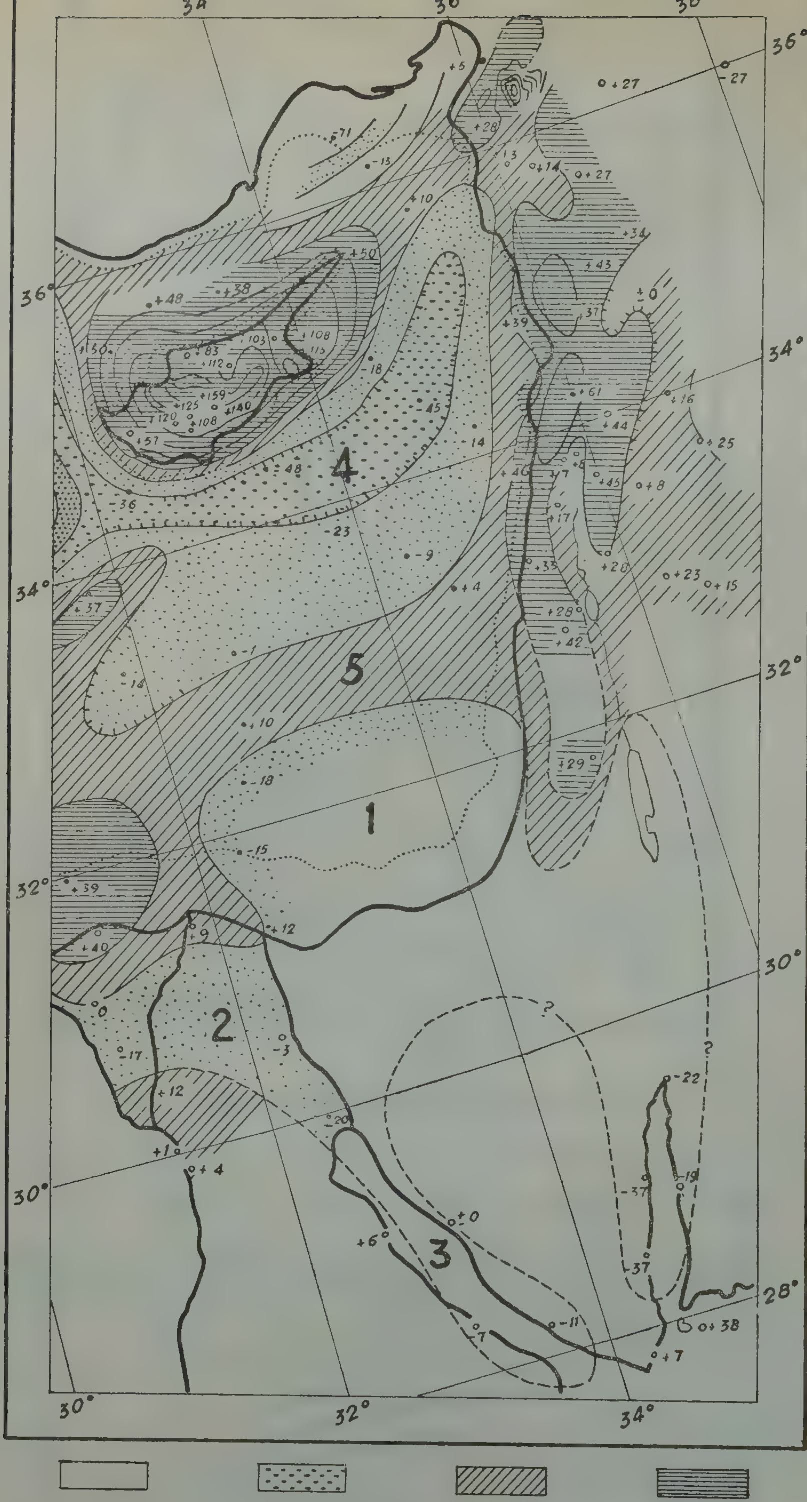


Figure 8

Cross-section: Heletz structure (conjectural)



0 to –25 | more than –25 | 0 to + 25 | more than +25

Figure 9
Interpretation of de Bruyn's Isogam map (Levant sector)
Regional Interpretation of De Bruyn's Isogam Map 1954
1 : 5,000,000
1. 2. 3. Ashkelon — Delta — Suez Basin, 4. Cuprus — Alexandretta Trough, 5. Levan
Isthmus

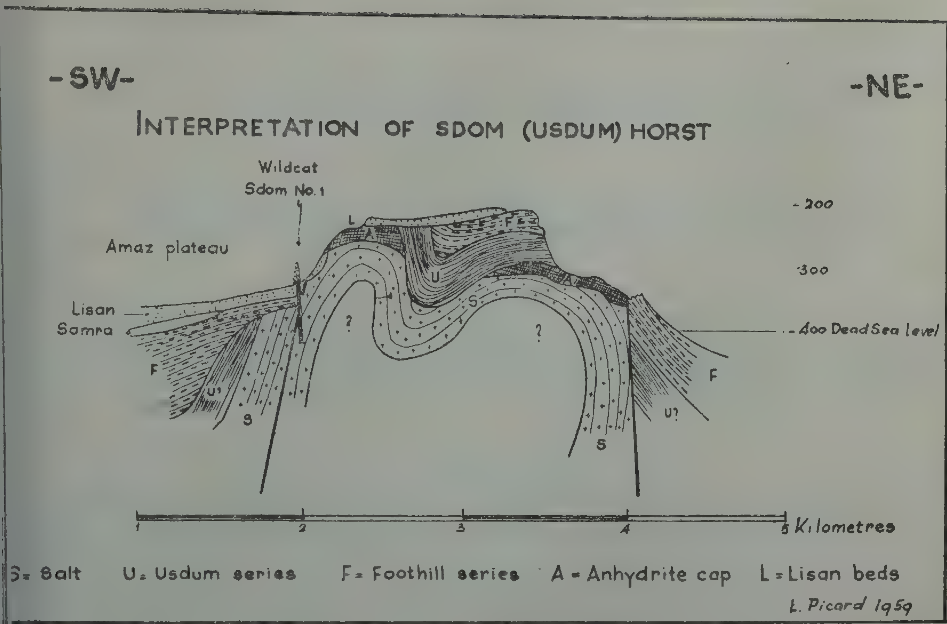


Fig 10

Cross-section: Sdom (Usdum) Mountain

A geological map of Israel and adjoining territories on a 1:500,000 scale, prepared by L. Picard and published by the Survey Department of Israel, will be enclosed with the next issue (Vol. 8 No. 2) of this Journal.

ON THE STRATIGRAPHY AND TECTONICS OF THE UPPER CRETACEOUS IN WESTERN GALILEE*

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ABSTRACT

The detailed stratigraphy of an area in western Galilee in which ammonites of the Lower Turonian occur is described. Marked facies changes occur over short distances, which may be attributed to early folding movements of a pre-Turonian age. There also seem to be indications of pre-Senonian fault movements.

INTRODUCTION

The following work was carried out in the hilly region on the western watershed of the mountains of Galilee. The mountains reach an elevation of 1000 m in the East and dip gently to the West towards sea level. Many faults dissect the area, mainly in an E–W trend, and form structures of horst gräben and tilted blocks (see map, Figure 1). The rivers usually follow the fault-structure trend. The hills are built of limestones, dolomites, chalk and flint of Cenomanian to Senonian age.

An important feature is the presence of ammonites from strata of Lower Turonian age which have been found in various parts of western Galilee. The boundaries of the area over which these ammonites are distributed have been known for some time and were roughly determined by Vroman (1958).

These ammonites of Lower Turonian age are found again at Beirut (Lebanon) in the North, in Transjordan in the East and in the Negev in the South.

During 1957–1958 a part of this area and its surroundings (from Kfar-Yasif in the West to Peqi'in in the East; see reference map, geologic map and Figure 2) was mapped in detail on a scale of 1:20,000 by the author, under the supervision of Prof. L. Picard.

From the detailed stratigraphical study made, Upper Cretaceous tectonic movements were discerned. Avnimelech, Grader, and Bentor and Vroman have already mentioned Upper Cretaceous tectonic movements in different parts of Israel.

STRATIGRAPHY

The area in which the ammonites of Lower Turonian age were found has been named the "central section". It is situated between the "lateral sections" which lie

* This paper is a summary of a thesis work carried out by the author for the M. Sc. degree of the Hebrew University.

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to the NW and SE. The boundaries of the central section may be defined as follows (see Figure 2): in the SE—an irregular line from Majd-el-Kurum to Kufr-Sumei; in the NW — a line from west Yirka to west Yanuch. The central section continues to the NE and SW beyond the area under review.

The lateral sections

The stratigraphic sequence (Lower Cenomanian–Senonian) found in the lateral sections resembles the usual columnar section found in central Galilee and is briefly summarized in the following table:

TABLE I

Stratigraphic sequence of lateral sections

Age	Name and symbol Previous*		Present**		Lithology	Thickness m
Campan. Maestr.	Senonian	s	Bini Chalk	s_2	Soft chalk, sometimes bituminous black flint	20+
Santon.			Kufr–Sumei Chalk	s_1	Hard white chalk	20+
Upper Turon.?	Turonian	t	Kisra Limestone	t_{2-3}	Lithographic limestone with stylolites ("Mizzi Hilu")	5–50
Cenom.–Turon.?	Upper–Cenom.	ce_3	Rosh–Tsurim Dolomite	c–ta	Coarse dark massive dolomite	150
Upper Cenom.	Middle Cenom.	ce_2	Peqi'in formation	c_2	Soft yellowish limestone, chalk and dolomite. Brown flint	22
Lower Cenom.?	Lower Cenom.	ce_1	Sajur Dolomite	c_1	Fine grey dolomite, well bedded	100+

* Picard 1956; Vroman 1958.
** Formation names given by the author.

The central section (*see Figure* 3)

The peculiar facies-changes which occur in the central section can be observed best south of Yanuch, in Wadi Kishk, and at Mugharat–Hamman.

Tufaniya chalk (c_2). The lowest formation which has been observed in the central section belongs to the Upper Cenomanian. Its type locality is at the foot of Kh. Tufaniya (Tufinim). It differs lithologically from the Peqi'in formation of the lateral sections by the prevalence of chalky facies, having less flint and no dolomite.

Yanuch formation (c–t b,c,d). This formation, which overlies the Tufaniya chalk, has its type locality below Yanuch village. It consists of three rock-units:

c–t b: white porous coarse limestone, as at Kh. Tufaniya

c–t c: chalk and fine white limestone with flint (very similar to c_2), as found below Yanuch and Yirka

c–t d: yellow lithographic limestone (very similar to the "Mizzi hilu" of the Kisra limestone, t_{2-3}), appearing on the slope of the hill north of Majd-el-Kurum.

The rock units appear in a different sequence at various places (fully described in the M. Sc. Thesis of the author). In the c–t b rock unit, prominent reefs (bioherm) occur. These are arranged in a line from Mugharat–Hamman (W of Majd-el-Kurum) to Kh. Tufaniya.

The thickness of the formation varies from 80 m in the middle of the central section to 145 m on its flanks. In the lateral sections, all the rock units change into the coarse dolomites (c–t a). No diagnostic fauna has been found except for a poorly preserved Protacantoceras sp. (?) (found near Jebel–Sabalan, outside and NE of the mapped area) which still suggests an Upper Cenomanian age.

Yirka formation (t_1). This formation overlies the Yanuch formation. The contact between them is very irregular, because of an angular discordance of t_1a over the above-mentioned reefs (c–t b). According to its ammonite fauna, this formation is Lower Turonian in age. The Yirka formation is well developed in the middle of the central section, where its thickness reaches more than 80 m, and may be divided into four members :

t_1a : Reddish laminated chalk and limestone in thin beds with flint; thickness 10–20 m. The fauna consists of: *Leoniceras luciae* Pervinquière, *Choffacticeras* c.f. *quasi* Peron, and a small ammonite (2 cm) —*Leoniceras* sp. (?).

t_1b : Coarse detritic, yellow limestone irregularly bedded with yellow marl; thickness about 25 m. The fauna consists of: *Thomasites rollandi* Thomas and Peron, *Thomasites jordani* Pervinqère, *Neptychites cephalotus* Courtiller, *Neoptychites xetriformis* Pervinquière, *Leoniceras luciae* Pervinquière, *Choffaticeras* c.f. *quasi* Peron, *Mammites* sp., *Natilus* sp.

t_1c : Soft white chalk which has yellow and blue colours in fresh exposures: thickness 10–15 m. The fauna consists of : *Thomasites rollandi* Thomas and Peron, a flat *Thomasites* sp. (?). *Leoniceras luciae* Pervinquère, and many still undetermined ammonities of the Mammitinae, Collignoniceratidae and Vascoceratidae.

t_1d : The lithology is similar to t_1b; thickness about 30 m. The fauna consists of : *Neoptychites cephalotus* Courtiller, *Pseudaspidoceras salmuriensis* Courtiller var., *Mammites nodosoides* Schlotheim, *Romaniceras deverianus* d'Orbigny, and many still undetermined ammonites of the above-mentioned families; *Plicatula* sp.; several species of *Sauvagesia.*

According to Parnes,* t_1d (on account of *Romaniceras deverianus* and some *Sauvagesia*) is stratigraphically equivalent to the "Dalia" marls of Mount Carmel and is, therefore, Upper Turonian in age.

* Personal communication.

Members t_1a and t_1c form a lens-like intercalation and are the first to disappear laterally from the middle of the central section; as a result, members t_1b and t_1d become combined. The Yirka formation thins out fast to the NW (over a distance of 500 m). To the SE it thins out gradually and irregularly, so that there it becomes indistinguishable from the formation lying above.

Kishk Limestone (t_2). The Kishk limestone which overlies the Yirka formation has its type locality in Wadi Kishk, where it forms cliffs. Where it is best developed, it is composed of coarse detritic yellow limestone, and attains a thickness of 60 m. In other places its thickness decreases to about 20 m and appears marly. Like the Yirka formation, the Kishk limestone is best developed in the middle of the central section, but its lateral distribution is much wider than that of the former. At the top there is a well developed fauna horizon, usually quartzitic, which contains *Nerinea requieni* d'Orbigny, *Acteonella* c.f. *sanctaecrucis* Futterer, *Sauvagesia* sp., *Sphaerulites* sp. (?), which point to Upper Turonian age.

"Stylolites" formation (t_3). Above the Kishk limestone follow 20 m of yellow lithographic limestone with stylolites and yellow marl. No fauna has been found. This formation is overlain by white hard chalk of the Santonian age, which, however, lies directly on t_2 west of Jatt.

The main characteristics in which the central section differs from the lateral sections may be summarized as follows :

1. A greater thickness from top c_2 to base s_1 (240 m instead 200 m).
2. Lack of dolomite.
3. Abundance of chalk and flint.
4. The phenomenon of bioherms (arranged in a line) unconformably overlain by younger formations.
5. Richness in fauna, especially ammonites and rudists.
6. An areal extent of 2–5 km by 25 km, with the longitudinal axis in a SW–NE direction.
7. Different rates of thinning out of the Turonian sediments.

CORRELATION

There are two possible ways to correlate the formations found in the central section with those described in the lateral sections.

1. Yanuch formation (c–t b,c,d), Yirka formation (t_1) and a part of Kishk limestone (t_2) may be the time equivalent of the Rosh Tsurim dolomites (c–t a). This seems less reasonable, as there are no lateral transitions from Yirka limestones and marls to Rosh Tsurim dolomites, while the lateral transition between the limestones and chalks of the Yanuch formation (c–t b,c,d) and Rosh Tsurim dolomites (c–t a) are clear. Moreover t_1 is found to lie in unconformable bedding upon

reefs of c–t b, where parts of t_1 (t_1a) terminate on the walls of the reefs. These reefs (c–t b) pass laterally to the dolomites of c–t a (see Figure 3).

2. The Rosh Tsurim dolomites (c–t a) may correspond only to the Yanuch formation (c–t b,c,d), and there seems to be no equivalent to t_1 and to a part of t_2 in the lateral sections. This seems more probable than the first possibility described. t_3 seems to correspond to the upper part t_{2-3}.

STRUCTURE

The stratigraphic changes described above have been explained in three ways in the author's M. Sc. Thesis : I. Dolomitisation which occurred only in the lateral sections and obliterated the original structure of the sediments. 2. Activity of reef-building organisms leading to lithological differences in the adjoining sediments. 3. Tectonic movements, i.e. subsiding of the central section floor beginning in the Upper Cenomanian. (As there are no outcrops of lower formations occurring in the area, it is impossible to determine if these movements started earlier.) It seems that the characteristics of the central section summarized above can be explained only in this way. As no fault could be detected along the borders of the central section, and as the thickness of sediments changes regularly, it seems that the central section is a syncline. There is, however, the difficulty of the absence of neighbouring anticlines and synclines which should occur in a regional folding.

The evolution of the area would be as follows :

1. Subsidence of the central section beginning in the Upper Cenomanian.

2. Growth of large "barrier reefs" (which afterwards became dolomitised) on the fringes of the depressed zone. Contemporaneously there settled fine sediments and "shoal reefs" inside the depressed zone.

3. Elevation of the whole area at the beginning of the Turonian limiting the sedimentation to the central section.

The absence of dolomite in the central section may be explained by the impermeability of the marls and chalks, which prevented magnesium solutions from penetrating and affecting the rock.

The region in which the Dalia marls occur in Mount Carmel seems to be the SW prolongation of the above-mentioned syncline.

Support for our assumption that Lower Turonian strata are found only in synclinal areas may be derived from Bentor and Vroman's geological map of the Negev (1951–1956). According to coordinates appearing in the text, the formation c_6 (Upper Cenomanian–Lower Turonian) is found along a SW–NE line from central Ramon through Har Teref, Nahal York'am and Machtesh Hatsera to Ein Bokek. This formation disappears or "becomes dolomitic" to the NW, at the Machtesh Hatira and Rosh Zohar. To the SE it thins out (only 2 m in Nahal Zin), and is characterized by a dwarf fauna. This formation, however, is underlain by gypsum salt and sandstones. The same phenomena of distribution of Lower Turo-

nian strata along a narrow strip in the SW–NE direction (crossing the Negev anticlines!) and different rates of thinning can also be observed here.

Blake (1936) mentions Lower Turonian strata in Transjordan in a similar facies to that of the Negev. These strata are found east of the Dead Sea from Wadi Hesa in the South to Wadi Mujib in the North, and disappear to the East and West.

It would thus appear that early folding movements already affected the Galilee (and perhaps the whole country) before the Lower Turonian.

Other interesting tectonic phenomena are little "gräben" in which small remnants of Senonian chalk abut against the fault margin. In one place, where no alluvial cover exists (SE of Yirka 1725/2616), Santonian is found in an angular discordance upon t_2 and t_3. It would thus seem that the fault movements of these gräben began before the Senonian. A supporting argument for this view is the total absence of Senonian on the elevated blocks. It should be noted that the SE formation boundaries of the central section bend inwards exactly where they reach the boundary faults of Jatt Majnuna gräben (see map and Figure 2).

ACKNOWLEDGEMENTS

The author wishes to express his gratitude to Professor L. Picard for introducing him to and guiding him in his Master Thesis work, to Mr. N. Schulman for his criticism of the manuscript, to Mr. P. Grader for helping him to prepare the English text, and to Mr. A. Parnes for his help in the macrofauna determinations.

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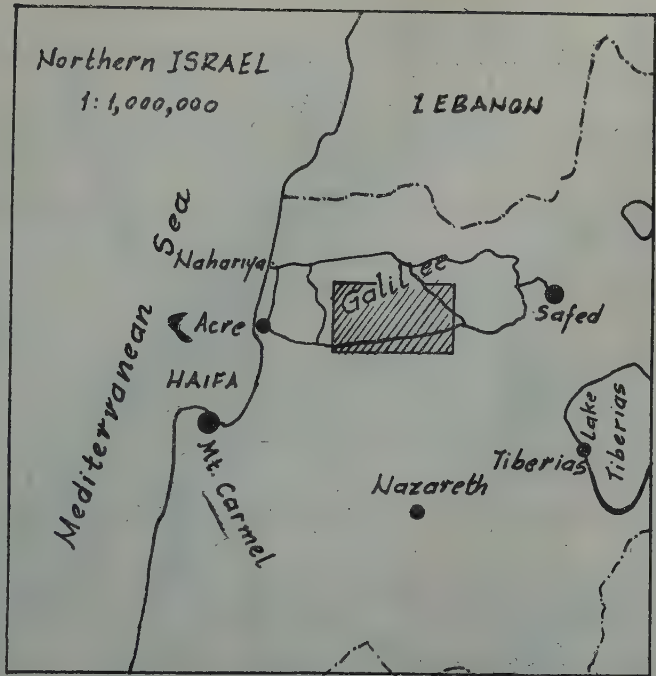

Figure 1
Reference map

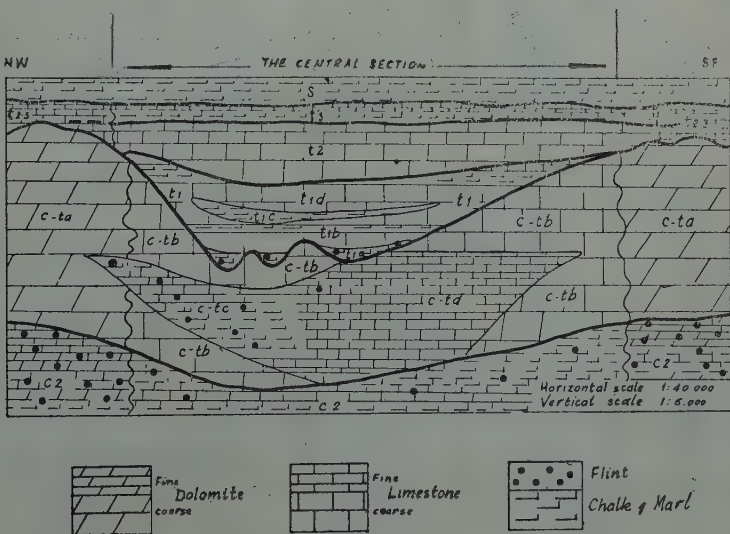

Figure 3
Schematic cross section through the central section

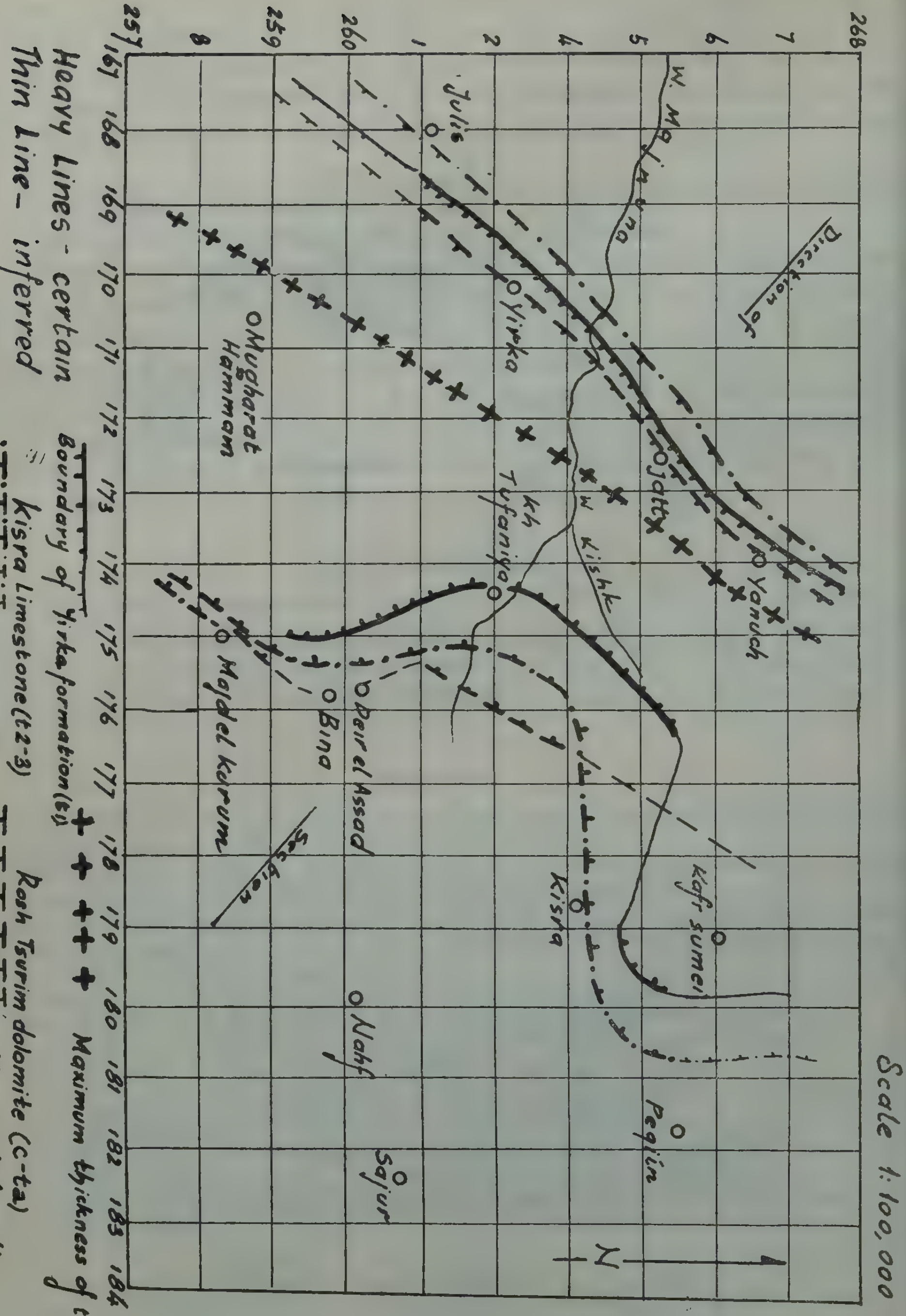

Figure 2
Boundaries of the central section formations

Figure 4
Geological map of Yirka-Peqi'in area, Western Galilee

THE OCCURRENCE OF GAS IN ZOHAR NO. 1*, NORTHERN NEGEV, ISRAEL

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ABSTRACT

Natural gas was discovered in the limestones of the top hard Jurassic in Zohar No. 1 at a depth of 1115–1260 m. The well is located on one of the small anticlines in the northern Negev, lat. 31°10′35″ and long. 35°10′35″.

At a production rate of 650,000 cu ft/day of gas and a delivery pressure of 615 psi, no water was produced with the gas. The static bottom hole pressure was measured at 892 psia.

I. INTRODUCTION AND ACKNOWLEDGMENTS

The recent discovery of gas in the top Jurassic limestone in Zohar No. 1 has substantially revived interest in the northern Negev as a potential petroleum province in Israel. Before Zohar No. 1 two unsuccessful exploration wells were drilled on two of the major anticlines of the Negev. Rekhme No. 1 (Grader 1957), located on the major culmination of the Rekhme chain, drilled to a total depth of 2766 m (9075 ft) and bottomed in the Triassic; no shows of oil or gas were reported. Kurnub No.1 was drilled to a total depth of 2773 m (9098 ft) and stopped in the Triassic or Paleozoic.

Zohar No. 1 is located on an anticlinal dome, which is stucturally the highest of the little anticlines between the main Kurnub (Hathira) anticline and the Judean Arc (Gwin and McGinty 1941, Jones and Rogers 1940).

The general area of Zohar was mapped by Y. Bentor and A. Vroman in greater detail (Bentor and Vroman 1954). The Zohar anticline and the adjacent Kidod anticline north of Zohar were mapped by E. Aharoni and partly by the author for the Naphtha Israel Petroleum Corp., Ltd.

The writer wishes to thank Mr. J. Coates and Mr. P. Grader for their assistance in preparing this note.

II. HISTORY OF DRILLING

Zohar No. 1 was spudded on June 17, 1957. The well started to drill with air, in order to overcome the serious loss of circulation zones in the Cenomanian and the upper part of the Lower Cretaceous. At 364 m (1196 ft) the formation became moist and it proved impossible to continue air-drilling with the equipment available.

The well then switched over to mud circulation. From 364 m (1196 ft) to 951 m (3120 ft) numerous losses of circulation occurred, but these could be shut off. At

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951 m (3120 ft) the circulation was again lost, and although many attempts were made, the circulation could not be regained. From here on till 1030 m (3379 ft) the well drilled blind until it reached the shales. At 1030 m (3379 ft) 7″ casing was set.

Losses of circulation occurred in the Jurassic, but these could be shut off with conventional methods. The well drilled without major interruption to its total depth of 1999.2 m (6559 ft), which was reached on March 4, 1958; $4\frac{1}{2}''$ casing was set at 1736 m (5663 ft) and the bottom part of the hole plugged off with a cement plug. The horizons with good oil-shows were perforated and swabbing tests made, in the 1360–1720 m range (4462–5643 ft).

After the swabbing tests inside the $4\frac{1}{2}''$ casing were completed the casing was shot at 1060 m (3477 ft) and retrieved. An additional swabbing test with the packer inside the 7″ casing then recovered gas at the rate of 135,000 cu ft/day (measured with Pitot tube), with a small spray of salt water.

Before the sidetrack was made, several zones in the Lower Cretaceous sands were perforated in order to locate a small gas flow escaping from the annulus between the $10\frac{3}{4}''$ and 7″ casing strings. Although the most promising horizons were tested, no gas was recovered in this upper range during the swabbing operations.

As no selective tests of the lower gas horizons could then be performed, because the cut-off $4\frac{1}{2}''$ casing could not be re-entered, the old hole was side-tracked and new $4\frac{1}{2}''$ casing was set at 1294.5 m (4245 ft) and several horizons perforated and swabbed.

III. STRATIGRAPHY

The stratigraphy of the upper part of the well is fairly well-established and is summarised in the following table:

Age of Formation	Depositional Environment	Lithology	Thickness in metres
Neogene	Terrestrial	Gravels and sands (HOSB series)	3
Campanian	Marine	Flint	15
Santonian	Marine (reducing)	Chalky marls with thin flint beds	22
Turonian	Marine	Massive and microcrystalline partly dolomitic limestone	74
Cenomanian	Marine	Limestone and marl including at the base 44 m of glauconitic sandstone, marl and limestone (greensand stage)	495
Lower Cretaceous	Marine to littoral	Limestone, shale and sandstone, some thin lignite beds	505
Jurassic	Marine mainly	Shale, limestone and sandstone (oil and asphalt shows in the sandstone and dolomite), dolomite, gypsum 535 m below the top hard Jurassic magmatic intrusion of dioritic to monzonitic magma in sandstones 28 m thick	More than 883 Thickness of the Jurassic not known

Recent micropaleontological investigations by Mr. Z. Reiss of the Geological Survey of Israel seem to indicate that the thick shale section at the base of the Lower Cretaceous (regarded up to now as the equivalent of the Berriasian shales of the Coastal Plain) are of Upper Jurassic age for at least the lower 50 m. As the microfossil evidence as to where to place the Lower Cretaceous–Jurassic boundary is not completed, we will adhere in the present paper to the working definition of "top hard Jurassic" for drawing the Lower Cretaceous–Jurassic boundary. The "top hard Jurassic" is defined as the first limestone bed occurrence below the Berriasian shales.

At 603 m below the top hard Jurassic, a thick body of dolomite with gypsum is recorded. In one possible correlation with Kurnub No. 1 this could be regarded as the top of the Triassic, but in general it is more probable that this is a separate and stratigraphically higher gypsum development.

The Neogene (HOSB Series) lies directly on the Campanian flint. The missing Upper Cretaceous and Lower Tertiary is found further eastward in the syncline. On the Zohar anticline the Campanian is also partly eroded below the Neogene: the thickness of the Campanian in Zohar No. 1 is 15 m (50 ft), as compared with 40 m (130 ft) in the syncline. In some place in the general area of Zohar the Santonian is missing or reduced in thickness.

IV. STRUCTURE

The Zohar anticline is an asymmetric anticline, as are most of the anticlines in the Negev. The east flank dips at approximately 35–40° into the Hatrura syncline, which continues with some minor undulations till the Dead Sea graben. The west flank dips gently at approximately 4–7° under the Neogene cover. The axis strikes NNE (Aharoni 1957).

The minimum fully mapped closure is of the order of 60 m (197 ft) but it seems reasonable to assume a total closure of 120 m (394 ft) on top Turonian, down to the saddle between the Zohar and Kidod structures (see Figure 2).

The Zohar anticline is separated from the big Hathita (Kurnub) anticline in the south by a broad saddle and from the Kidod anticline in the north (standing slightly in echelon to the Zohar anticline) by a shallow and narrow saddle (see Figure 2).

From the reduced thicknesses and hiatuses in the stratigraphic section from the Turonian upwards it seems that undulatory movements have been present from the end of the Turonian to the Miocene. However, future study may reveal that movements earlier than post-Turonian have acted in the general area of Zohar. The final folding took place in the end of the Oligocene and Miocene (Picard 1943).

V. GAS OCCURRENCE

During the drilling of Zohar No. 1, no gas was noticed in the drilling mud, although a close watch was kept at all times. This is not now surprising in view of the low formation pressures recorded; the formation pressure is about 55 atm (810 psi) less than the hydrostatic pressure.

The presence of gas in the limestone beds of the top hard Jurassic was originally suspected from the electrical and neutron log. A swabbing test made from the perforations at 1212–1214 m (3982–3989 ft) in the middle of a porous limestone bed to verify this possibility recovered mud from behind the casing but failed to yield gas.

There is another gas occurrence, separate from the Jurassic gas now tested, in the Lower Cretaceous. This was detected as a gas escape at the surface between the 7″ and $10\frac{3}{4}$″ casing strings, but after re-cementation and perforation the source could not be found.

After $4\frac{1}{2}$″ casing was cut and retrieved, an additional swabbing test was made. After emptying the hole, gas started to flow at the rate of 135,000 cu ft/day. On account of this the old hole was sidetracked and new $4\frac{1}{2}$″ casing was set.

The perforating programme was now based on the postulate that the gas escapes from the formation mainly at the interfaces of shale and limestone (the previous test at 1212–1214 m within the body of a limestone bed did not recover gas). The perforating was carried out in three stages; these are partly overlapping, and acidization was done between the perforation operations, which makes the evaluation of the production of each perforation rather arbitrary.

The first perforation (see also Figure 2) was made at:

1261.5–1263.5 m (4138–4144 ft)

No gas was recovered.

In the second stage perforations were made at:

1161.0–1163.0 m (3809–3815 ft)
1165.5–1167.5 m (3823–3829 ft)
1187.0–1189.0 m (3894–3900 ft)
1194.5–1196.5 m (3919–3925)

Gas flowed at a rate of 324,000 cu ft/day (Pitot tube), and a small spray of water from which 8,000 cu ft/day (estimated from pressure build-up on separate testing) were contributed by the lower perforations. After acidizing, using 33 bbls of HCl 15%, the total production increased to 770,000 cu ft/day (Pitot tube).

The third series of perforations are listed below in the order in which they were tested.

Perforations at:

1228.0–1230.0 m (4030–4036 ft)
1232.2–1234.2 m (4043–4049 ft)
1241.3–1243.3 m (4072–4078 ft)

The swabbing test failed to recover gas.

Testing the perforations at:

1187.0–1189.0 m (3894–3900 ft)
1194.5–1196.5 m (3919–3925 ft)

plus additional perforations at:

1201.0–1203.0 m (3940–3946 ft)

1208.1–1210.1 m (3963–3969 ft)

1214.2–1216.2 m (3984–3990 ft)

1217.2–1219.2 m (3993–3999 ft)

gave 116.000 cu ft/day (Pitot tube) and a small spray of water.

The perforations at:

1115–1121 m (3658–3678 ft)

were tested and acidized with 37 bbls HCl 15%, but the measured rate of gas flow are not considered reliable, as the packer which was used as bridge plug to shut off the lower producing horizons may have failed.

The production from all perforations listed above measured 1.2 million cu ft/day (Pitot tube) and a small spray of water.

After the well-head equipment was connected up, a series of back-pressure tests were run to determine the well capacity and bottom hole pressures. With a shut-in pressure of 892 psia at 1164 m (3819 ft), the tests resulted in the following data for gas flow measured 16 hours after opening of the well:

Choke in 1/64″	Back-pressure at 1164 m (3819 ft) well-depth in psia	Well-head pressure in atm	Flow in Mill. cu ft/day
6	873	55	103
8	841	52	252
10	798	50	448
13	739	46	654

No water had accumulated in the separator during these tests. From the draw downcurve over a range of 20 hours it was seen that no stabilization had occurred at the end of this interval.

A prolonged test on 14/64″ choke for a week was made in order to determine the stabilized production. This test seems to indicate that stabilization occurs after 48 hours.

The production after 144 hours on a 14/64″ choke was 648,000 cu ft/day at well-head pressure of 42 atm. The inferred open-flow capacity of the well after stabilization through 2″ tubing is 1.4 million cu. ft/day. The total production between the first and the last shut-in pressure tests was 6.6 million cu ft/day. The bottom hole pressure remained constant within the accuracy of measurement.

The analysis of the gas, made by The Weizmann Institute of Science in Rehovot, shows the following composition:

Methane	94.2%
Ethane	2.4%
H_2S	None
Remainder	Air

The analysis of the water recovered with the gas was performed by the Oil Division in Jerusalem, Israel, and gave the following composition in ppm:

Na	5257	Cl	9447
K	109	SO_4	1050
Ca	777	CO_3	—
Mg	233	HCO_3	365

VI. SUMMARY

After the initial failure of two wildcats in the Negev, the discovery of gas in Zohar No. 1 has enhanced the interest in this area considerably.

Zohar No. 1 is located on one of the smaller anticlines of the northern Negev. The anticline is exposed in most places on the flanks to the Turonian limestone. A closure of 120 m is considered probable.

The drilling has been both difficult and expensive, owing to the severe losses of circulation and the difficulty of bringing water to the location.

The electric logs suggested the presence of gas, but the first direct test by perforation was negative and the potentialities only became apparent later after removal of part of the casing.

The reservoir rocks are the limestone beds of the top hard Jurassic at the depth of 1115–1260 m (3658–4133 ft).

The limestone beds below 1226 m (4000 ft) did not yield gas when tested, but it remains to be seen whether here too production may be obtainable, if the formation is treated (acidizing of fracturing).

The shut-in pressure at 1164 m (3819 ft) is 892 psia.

The open flow capacity is calculated at 1.4 million cu ft/day.

At high rates of flow a small spray of salt water was originally produced with the gas.

A production of 650,000 cu ft/day at a delivery pressure of 615 psi (42 atm) is considered practical. At rates of flow up to 700,000 cu ft/day no water was produced with the gas.

The gas is substantially methane with some ethane; no higher homologs are found.

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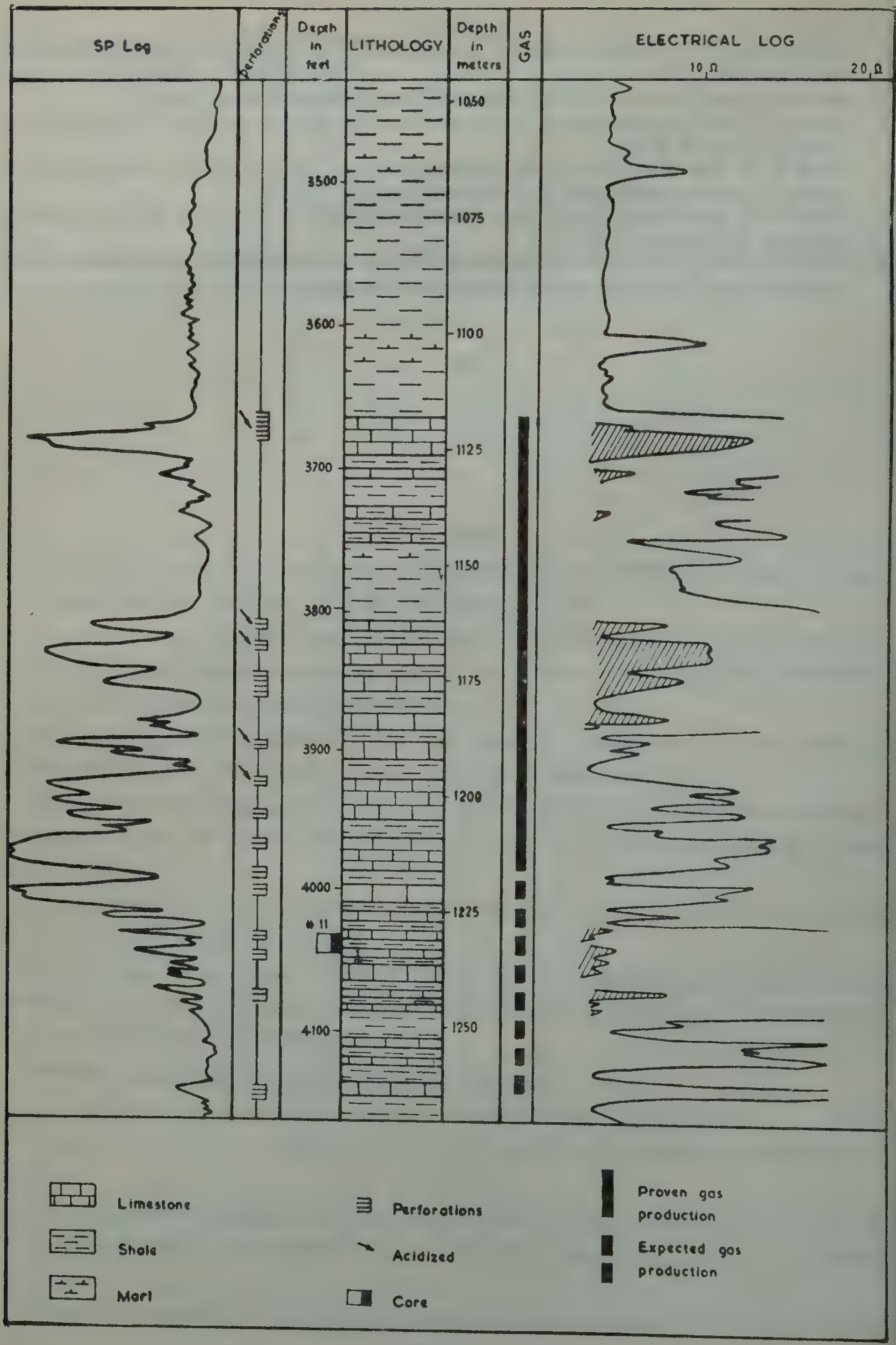

Figure 1.
Zohar No. 1. Portion of well log over gas occurrences

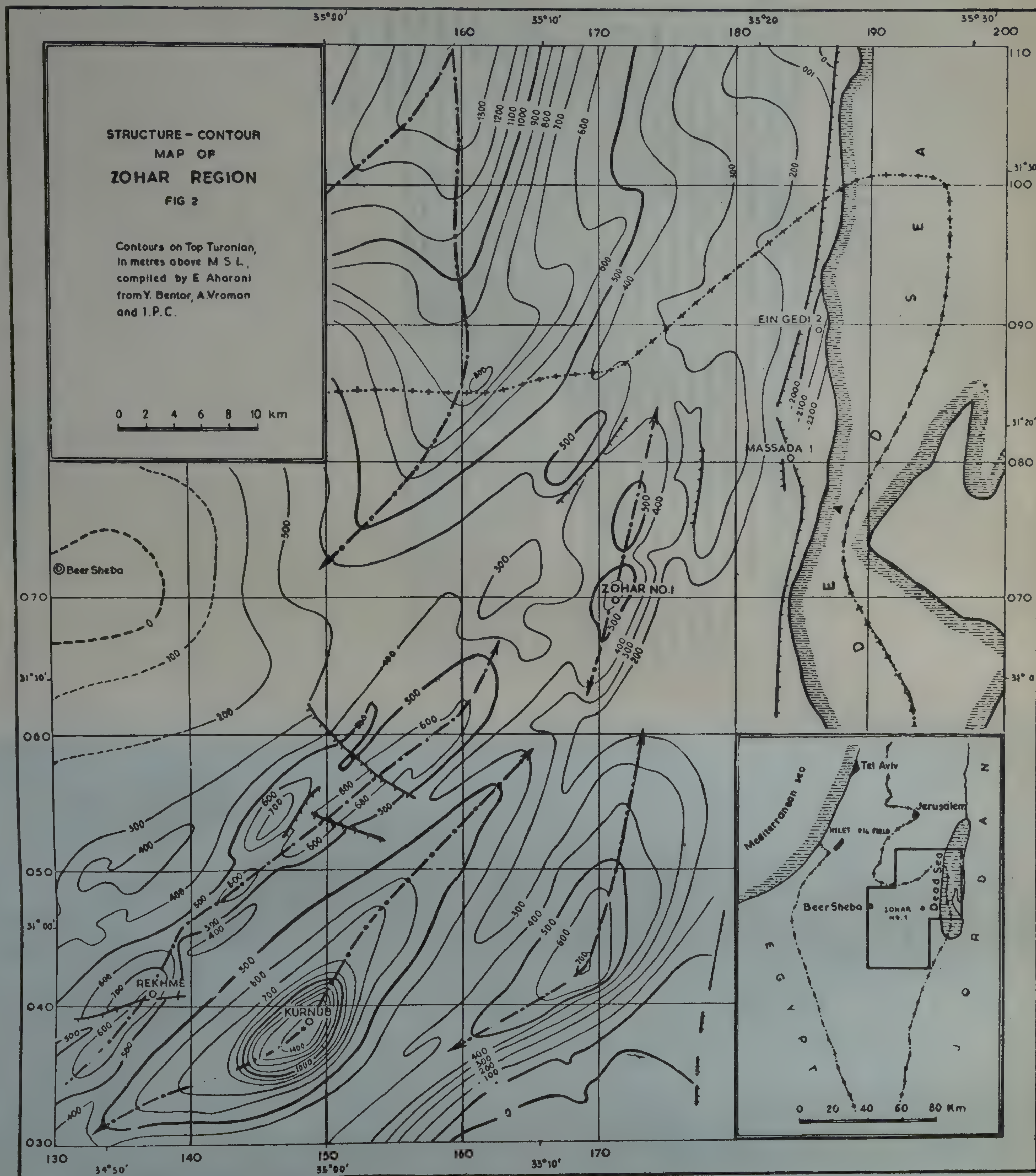

Figure 2.
Structure-contour map of Zohar region

LETTER TO THE EDITOR

SUPPLEMENTARY NOTE ON THE OCCURRENCE OF THE GENUS *BATHYSIPHON* (FORAMINIFERA: MONOTHALAMIA) IN THE LOWER EOCENE OF ISRAEL

M. Avnimelech, *Department of Geology, The Hebrew University of Jerusalem*

In my paper "Occurrence of the genus *Bathysiphon* in the Eocene of Israel" (Contrib. Cushman Found. Foramin. Res., IV, 1, 1953), I have recorded the occurrence of this genus in the Lower Eocene of Givat Hamoreh, East of Nazareth, and in the north-eastern border of the Megiddo syncline (Menashe mountains) south-east of Haifa. Recently, I have observed similar rocks containing a great number of *Bathysiphon*-tubes (cf. *B. taurinensis* Sacco) in an area approximately 6 km east-southeast of Shefaram town, on the way to Nazareth.

These additional observations show that this foraminiferal genus existed in vast areas of the Lower Eocene sea, East and North of the Carmel, and in the Lower Galilee. It is also apparent that in spite of its extremely primitive shape, *Bathysiphon* can be considered as a regionally useful fossil of the Lower Eocene because it has not been encountered until the present day below or above this horizon.

Microscopic examination of the rock sample from this locality revealed—as in the case of the rocks of Givat Hamoreh—that it consists mainly of *Radiolaria* with relatively few *Globigerina* and *Globorotalia* and isolated *"Bolivina"* and *"Nodosaria"*. This again indicates—as pointed out in my former paper—a rather deep water facies (possibly more than 1000 m) which prevailed in this part of the country. On the other hand, in the central and southern regions (Negev), where no *Bathysiphon* occurrence was observed until now, the sea was probably less deep. If this is true, it may be concluded that the area around the Carmel and the Lower Galilee has played a special rôle in the palaeogeography of the Lower Eocene.

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CORRIGENDA

to article "Geolgy and Oil Research of Israel" by Prof. L. Picard,
Bull. Res. Counc. of Israel, G8, p. 24.

p. 15, 1. 2: *for* by migration *read* by lateral migration
1. 3: *for* (in S_2) *read* (in CS_2)

p. 30.: Add to references:

HUDSON, R. G. S., 1958, The upper Jurassic Faunas of Southern Israel, *Geol. Magaz. (London),* 95, 415.

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המועצה המדעית לישראל - משרד החנוך והתרבות - האוניברסיטה העברית בירושלים
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